United States Department of Agriculture

Forest Service

North Central Forest Experiment Station

Resource Bulletin **NC-130**

Properties of Soils and Tree Wood Tissue Across a Lake States Sulfate Deposition Gradient

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Manuscript approved for publication June 6, 1991
1991

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There is general concern that atmospheric pollutants may be affecting the health of forests in the USA (Barnard 1986). In response to that concern, in 1985 we began a program of research on the relations between forest condition and atmospheric deposition across the Great Lakes region. Because widespread forest damage or decline is not visibly evident in this region, the research was aimed at detecting subtle regional trends related to acidic deposition in general and to sulfate deposition in particular. The hypotheses tested were that the wet sulfate deposition gradient across the Lake States (Harris and Verry 1985, Verry and Harris 1988): (1) is reflected in the amount of accumulated sulfur in the forest floor-soil system and tree woody tissue and (2) is related to differences in tree radial increment. We also hypothesized that these relations can be distinguished from those related to site and climatic variation across the region (Ohmann *et al.* 1987, 1988; Holdaway 1989; Shifley 1988; David *et al.* 1988; Grigal and Ohmann 1989; Ohmann and Grigal 1990).

An earlier report (Ohmann *et al.* 1989) detailed the physical characteristics of 171 study plots that were established across the acidic deposition gradient to test the general hypotheses. That report included particle-size analyses of soils by zone and forest type and may be useful in interpreting some of the soil chemical data in this bulletin. Here we present the properties of the soil and tree woody tissue (mostly chemical) on the study plots. Knowledge of the properties of soil and woody tree tissue is needed for understanding and interpreting relations between sulfate deposition, sulfur accumulation in the ecosystem, soil and tree chemistry, and tree growth and climatic variation. This report provides a summary of those data for study, analysis, and interpretation.

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METHODS

Plot Selection

The data were collected across the forested portions of Minnesota, Wisconsin, and Michigan. Plot selection has been documented in detail (David *et al.* 1988, Grigal and Ohmann 1989). Briefly, a stratified random sample of 171 USDA Forest Service inventory plots within the three States was selected (fig. 1). The sample was stratified to balance the plots geographically and among five forest types: balsam fir (*Abies balsamea* (L.) Mill.) (n=26), northern hardwoods dominated by sugar maple (*Acer saccharum* Marsh.) (n=41), jack pine (*Pinus banksiana* Lamb.) (n=39), red pine (*Pinus resinosa* Ait.) (n=27), and aspen (*Populus tremuloides* Michx.) (n=38). Although 171 plots were sampled, two balsam fir plots were dropped from most of the analyses because high organic content of the soils indicated that they did not meet the plot selection criterion of being located on well-drained upland mineral soil. In most cases, data from those two plots were outliers. The sampled plots occurred on a variety of landforms; about one-fourth were on soil mapping units dominated by Alfisols, one-fourth on Entisols, one-fourth on Spodosols, one-sixth on Inceptisols, and one-tenth on other soil orders or on unmapped soils (Ohmann *et al.* 1989).

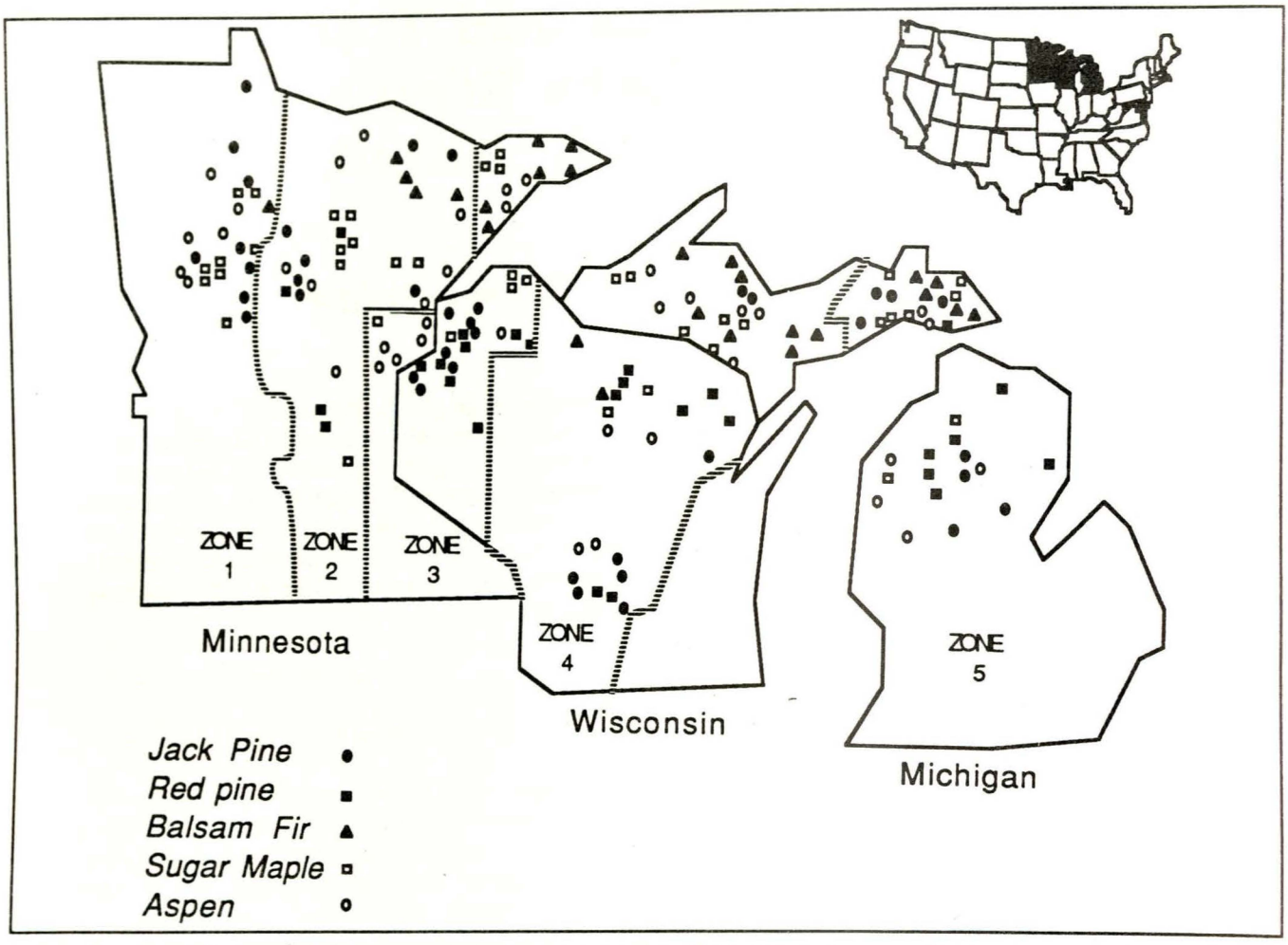

Figure 1.—*Distribution of plots sampled along an acid sulfate deposition gradient across the Lake States.*

Forest Service inventory plots are clusters of 10 subplots arranged in roughly an elliptic configuration; measured (tally) trees are selected with a probability proportional to their size (Doman *et al.* 1981). Total area of the 10 subplots is about 0.4 ha. At every other subplot (total = 5), we selected a dominant or codominant (non-tally) tree of the most prevalent species on the plot and used it to define a location for soil and tree wood tissue sampling.

Field Sampling

One forest floor sample was collected at 1.5 m from the selected trees at each of three azimuths—45°, 135°, and 225°. At each location, a stainless steel ring (12 cm diameter) was forced through the forest floor, and the forest floor thickness was measured (to 5 mm) at four points within the ring. All organic material was collected down to the mineral soil surface. This sample therefore included all O horizons, as well as sticks and roots within those horizons. In mull humus types, the forest floor was nearly exclusively the Oi horizon; in mor types, it contained Oi, Oe, and Oa horizons. The collected material was placed in Whirl-pak[1] plastic bags, cooled immediately, and frozen in the laboratory (usually within 48 hours).

Because this study was an extensive survey of many sites rather than an intensive study of a few sites, we sampled mineral soils by uniform depth increments rather than by description

[1] *Use of trade names does not constitute endorsement of the product by the USDA, Forest Service.*

and sampling of pedogenic horizons exposed in excavated pits. The only data available that provides information on soil morphology are the descriptions of the soil mapping units upon which each plot fell and the description of the major soils in those mapping units (see Ohmann *et al.* 1989). Our rationale for this approach to soil sampling was based on four reasons: (1) We used a bucket auger to sample soils because of the plot sampling design that included a large number of soil samples on each plot to capture soil property variation. Excavating the equivalent number of pits would have been too costly and time consuming. The auger significantly disturbs the soil morphology, making separation of pedogenic horizons difficult. (2) Several crews were used for sampling, raising a concern that soil descriptions would not be uniform among crews. Differences in resulting descriptions and sample analysis results could have been attributed to a "lumper" versus "splitter" approach to soil description and sampling, with the possibility that one crew would recognize many more soil horizons than another. (3) Budgeting required a good estimate of the number of samples to be analyzed, and we developed our budget and laboratory capability in anticipation of that number. Because of the variety of soils that occur across the gradient and the potential variation in personnel as described above, sampling by pedogenic horizon would have yielded an unknown number of samples. (4) A major objective of the study was an inventory of the total amount of sulfur and other elements in the soil. This objective necessitates analysis of all soil horizons. Some horizons are very thin or discontinuous. In sampling by pedogenic horizon, samples from such horizons are very often either not collected or they are added to a sample from the horizon above or below. Either the omission of a sample or bulking violates the concept of analysis by pedogenic horizon.

At each point where forest floor samples were collected, the upper 25 cm of mineral soil was sampled with a bucket auger. Depending on the morphology of the soil, this sample may have included material from A, E, and even the upper B horizons. Each sample was thoroughly mixed on a polyethylene sheet using a plastic spatula; and a quartered subsample of the original sample, or around 500 g, was placed in a Whirl-pak plastic bag, cooled, transported, and frozen as with the forest floor samples.

At one of the forest floor sample locations at three randomly selected sample trees, augering was continued to 1 meter, and samples were collected from the 26 to 50 cm, 51 to 75 cm, and 76 to 100 cm depths. These samples were composited in the field to yield one sample for each 25 cm depth from each inventory plot. These samples were treated in the same way as the surface mineral soil samples.

Mineral soil bulk density was sampled using the irregular-hole method (Howard and Singer 1981) at 1.5 m from each sample tree at a 315° azimuth. Forest floor was removed from the surface and two determinations of bulk density were made, one of the upper 12.5 cm of soil and the second of the 12.6 to 25 cm depth. Excavated samples were treated in the same way as the other mineral soil samples.

Increment core samples were collected from each sample tree to measure radial growth increment and to determine chemical concentration in woody tissues. The dominant or codominant (non-tally) tree that was selected was required to have a diameter at breast height within 2.5 cm of the current plot mean diameter and to be representative of the topographic position of the plot. At least nine cores from each sample tree (a minimum of 45 cores per plot) were collected with a stainless-steel or teflon-coated increment borer at breast height to determine nitrogen (three cores), sulfur (three cores), and other elements (three cores). The cores included a minimum of 30 years of annual growth rings. Cores were placed in plastic straws labeled by tree and stand, and were kept frozen until processed.

Laboratory Analyses

Soils

After thawing in the laboratory, the three forest floor samples associated with each tree were bulked and macerated in a commercial stainless-steel food processor to < 5 mm. This procedure also homogenized the sample. One

subsample was removed, oven-dried (75° C), and ground to pass a 40-mesh screen, using a stainless-steel Wiley mill; another was kept moist at 4° C.

When thawed, the three mineral soil samples associated with each sample tree were also bulked and sieved while moist through a 3-mm sieve. We used a 3-mm sieve to separate fine earth because we were sieving field-moist samples. Most soil analyses are based on a fine-earth fraction less than 2 mm in diameter. Our exploratory work demonstrated that it would be difficult to pass moist fine-textured material through a 2-mm sieve because of the presence of structural peds. In evaluating the difference between analytical results based on a 3-mm definition versus a 2-mm definition of fine-earth, the critical question is the amount of material that falls in the narrow size range of 2 to 3 mm. Material in this range would be slightly larger than material defined as very coarse sand (1 to 2 mm). This class of large material contributes virtually nothing to either soil chemical properties (*i.e.*, it has very low cation exchange capacity, nitrogen, etc.) or to hydraulic properties. It primarily acts as a dilutant of the traditionally defined fine-earth fraction.

Three approaches can be used to estimate the material present in the size range of 2 to 3 mm. First, the amount of material in the very coarse sand size class may provide a maximum limit for the material from 2 to 3 mm. The Soil Survey Laboratory data base at the University of Minnesota contains records of 20,300 soil samples collected throughout the State. Less than 4 percent of the samples contained more than 10 percent very coarse sand. Of the 14,800 samples in which very coarse sand was measured, the average amount found was 2.7 percent.

Second, the amount of material in the samples that is larger than 3 mm can be examined. In the samples that we collected along the gradient, we weighed the mass of rock greater than 3 mm (up to around 20 mm); that material averaged 3.7 percent by weight. The fraction of material from 2 to 3 mm would likely be much less than the 3.7 percent that was larger than that size class.

Third, we have limited data on the actual amount of the soil material in the range of 2 to 3 mm. In a random subset of our samples (n=20), ranging from 43 to 92 percent sand with a mean of 69 percent, the average amount in the 2 to 3 mm size range was 0.8 percent by weight. About one-third of those samples had more than 1 percent in the 2 to 3 mm size class, and the maximum was 2.5 percent.

All three approaches indicate that the difference between the traditional definition of fine earth as material less than 2 mm compared to our definition of less than 3 mm is on the order of 1 percent by weight. Based on that reasoning, dilution would reduce the values that we have determined for chemical and physical properties by around 1 percent compared to values that would be based on the traditional definition of fine earth. Although this is a systematic bias, it is much less than the spatial variation in soil properties that occurs within a forest stand (Grigal *et al.* In press).

After sieving, soils were mixed by quartering and a subsample was oven-dried (105° C) and ground to pass a 40-mesh screen; the moist remainder was retained at 4° C. The oven-dried samples were used for analysis of nitrogen (N), sulfur (S), carbon (C), loss on ignition (LOI) (David *et al.* 1988), and total elemental analysis of the forest floor (Grigal and Ohmann 1989). The moist samples were used for analyses of exchangeable calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), exchangeable acidity (Ac), cation exchange capacity (CEC), and pH. In all cases, results were adjusted to an oven-dry weight basis with moisture data from dried subsamples.

The samples of both forest floor and surface mineral soil were analyzed for total S using a LECO SC-132 automated analyzer, for total N by semi-micro Kjeldahl, for LOI by ashing at 450° C, and for total C on 20 percent of the samples using a LECO CR-12 analyzer (David *et al.* 1988). Exchangeable cations were extracted using 1 *M* NH_4NO_3, and Ca, Mg, K, and Na were determined by atomic absorption spectroscopy. Exchangeable acidity was determined by titration (Stuanes *et al.* 1984). Solution concentrations were converted to soil concentrations. Determination of pH was in 0.01 *M* $CaCl_2$ with a

dry weight soil:volume of solution ratio of approximately 1:2 for mineral soil samples and 1:10 for forest floor samples. Coefficients of variation for soil sample data have been reported in Grigal *et al.* (In press).

Excavated mineral soil samples for bulk density were dried at 105° C, weighed, and sieved through a 2-mm sieve; dry weight of material greater than 2 mm (rock) was determined; and sample volume was corrected for rock by assuming rock density as 2.6 Mg m^{-3}. After computing the bulk density of fine earth from the corrected weight and volume, we computed a mass-weighted mean density at each sample tree from the densities of the two increments (Grigal *et al.* 1989).

We calculated a mass per unit area of S, C, N, and exchangeable Ca, Mg, K, and Na, for forest floor and mineral soil from bulk density, concentration, and thickness data (corrected for volume of stone) for both layers. Values for both layers were summed and divided by total mass of those layers to arrive at a mass-weighted mean concentration for each plot.

Wood tissue

The tree cores were thawed, and the 1956-1985 growth was divided into three 10-year growth periods. Length of each increment was measured; and then increments were grouped with others of the same growth period from each tree (*i.e.*, all 1956-1965 segments aggregated), and oven-dried at 65° C.

We analyzed for total S by inductively coupled plasma atomic emission spectrometry (ICP -ARL model 34000), using a digestion procedure originally adapted from Johnson and Ulrich (1959); and we analyzed for nitrogen (N) by semi-micro Kjeldahl (Ohmann and Grigal 1990).

Wood tissue samples were analyzed for total elemental concentration by ashing (around 1 g) overnight in a muffle furnace at 485° C. After cooling, ash weight was determined and recorded. Five milliliters of 2 *M* HCL was added to the ash, and the crucibles were covered and placed on a hot-plate at near-boiling of the acidic solution for 30 minutes. Acid was added to the solutions in the crucibles after cooling, to restore them to original weight. An additional 5 mL of HCL was then added, and the covered crucibles were allowed to stand overnight. Solutions were then transferred to tubes for analysis of Al, B, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, and Zn by inductively coupled plasma atomic emission spectrometry (ICP, ARL model 137). We evaluated our analytical accuracy by comparing results of samples from the National Bureau of Standards (NBS). We evaluated our precision by both carrying a standard check sample of wood tissue through the analytical procedure with every batch of samples and by analyzing duplicate samples.

Atmospheric Deposition

Mean annual precipitation was estimated for each plot from 30-year normal precipitation data (1951-1980) for the nearest weather station. Wet sulfate concentration for each plot was estimated by using an equation relating sulfate concentrations from the 1983 National Atmospheric Deposition Program (NADP) to latitude and longitude (Shifley 1988). The year 1983 was chosen for analysis because a complete set of data for wet deposition was available for that year. Although deposition differs from year to year, west-east trends were similar in other years for which partial data were available (Shifley 1988). Plot-specific deposition was considered to be the product of the estimated precipitation and concentration (David *et al.* 1988).

Statistical Analyses

For all statistical analyses reported in this bulletin, plot means were calculated for forest floor, mineral soil layers, and 10-year growth increments of wood tissue for each element measured. Analysis of variance (ANOVA) was used to test means among zones and forest types, and for each forest type among zones across the gradient. Where ANOVA P values were <0.10, least significant difference at the 0.95 percent probability level was used to test for differences among means.

RESULTS AND DISCUSSION

Sulfate Deposition

Estimated atmospheric wet sulfate deposition increased consistently from west to east (zone 1 = 7.5, zone 2 = 10.0, zone 3 = 11.8, zone 4 = 16.3, and zone 5 = 18.3 kg ha^{-1} $year^{-1}$). The difference among zones in sulfate deposition was highly significant (F = 354.5, df = 4,168) with a Bayes Least Significant Difference among means of 0.5 kg ha^{-1} $year^{-1}$ (Ohmann and Grigal 1990).

Total Mean-Weighted Soil

Tables 1.1, 1.2, and 2.1 detail the properties of the forest floor and the 0 to 25 cm mineral soil combined on a mean-weighted basis across the sulfate deposition gradient. Base saturation, pH, cation exchange capacity, and exchangeable Ca, Mg, and K all decreased significantly from west to east across the gradient. The other properties—C, N, S, loss-on-ignition, and exchangeable Na—did not show any general pattern related to the gradient, although some of the differences among the zones are statistically significant (table 1.1). All the measured properties exhibit a significant difference among the five forest types (table 1.2). In general, mean values are lower for the soils of two of the conifer forest types, jack pine and red pine, than for the soils of the two deciduous forest types, sugar maple and aspen. For most properties, the mean soil values for the balsam fir type are more similar to those for the aspen type than to those for the conifer types; and in some cases, the balsam fir soil values exceed those for the deciduous types, for example, C, N, and S (table 1.2). Balsam fir forest type soil particle size distribution was also reported to be more similar to the deciduous than to the conifer forest types (Ohmann *et al.* 1989). When the properties are tested by individual forest types, there are many fewer statistically significant differences among the zones. This is probably due to the reduced number of observations for each forest type in each zone. In general, the two forest types with the most observations, sugar maple and jack pine, also show the largest number of significant differences among zones (table 2.1). The trend of magnitude of most soil properties decreasing from west to east across the zones of the deposition gradient is also evident when the data are presented by individual forest type, even where the differences among zones are not statistically significant. Differences in soil properties among naturally occurring forest types are also obvious (table 2.1); such differences are not always recognized by those less familiar with forest soils.

Forest Floor

Tables 3.1, 3.2, 4.1, 5.1, 5.2, and 6.1 detail the forest floor as a single unit. All but one of the measured forest floor properties are significantly different among zones across the gradient (table 3.1). Most of the values decrease from west to east across the gradient: base saturation, pH, cation exchange capacity, exchangeable Ca, Mg, and K. A few show a bimodal trend, either higher (bulk density) or lower (LOI and N) values in the middle zone of the gradient. Sulfur shows a higher value only in zone five on the eastern end of the gradient (table 3.1). All the measured forest floor properties are significantly different among forest types, and the relationships among the data (table 3.2) are similar to those discussed previously for the weighted data. More of the values for individual forest types are significantly different among zones for the forest floor alone (table 4.1) than were significant for the total mean-weighted forest floor plus upper mineral soil; the trend of a decrease in magnitude of forest floor values from west to east across the deposition gradient is similar to those in table 2.1. Total elemental concentrations, except for Cd, Cu, and Zn, are all significantly different among zones across the gradient (table 5.1) and among forest types (table 5.2). The pattern of distribution of the elemental concentrations in relation to the sulfate deposition gradient has been described and interpreted by Grigal and Ohmann (1989). Based on results from other studies on the association of aluminum with soil acidification processes, one might expect to find forest floor elemental Al concentrations to increase with sulfate deposition across the zones of the gradient. The trend in our data is the opposite, one of decreasing Al concentrations from west to east for all five forest types (tables 5.1 and 6.1). Some metals—Cd and Pb—did generally increase across the gradient for most forest

types; others did not—Cr, Fe, Mn, Ni, and Zn (table 6.1). The concentration of major elemental nutrients in the forest floor generally decreased from west to east across the gradient for each forest type (table 6.1) as described for the general case of all five forest types (table 5.1) by Grigal and Ohmann (1989).

The high base saturation values for the forest floor and for forest floor - mineral soil combined require additional comment. High base saturation but relatively low pH in the forest floor is indicative of the nature of the exchangeable acidity in that layer. In mineral soils, most of the exchange acidity is in the form of exchangeable aluminum; but in the forest floor, it is almost exclusively associated with the hydrogen ion. In addition, we used the effective (neutral salt) cation exchange capacity (CEC) to calculate base saturation. This yields much lower CEC than do buffered methods, especially in the high-organic forest floor. In our data, as forest floor pH approaches 6.2 (in 0.01 *M* $CaCl_2$), exchangeable acidity is at the detection limit and base saturation is 100 percent. Although not presented in this report, pH of the forest floor in water is about 0.6 units higher than that in calcium cloride; values of 100 percent base saturation are therefore near pH 7.

Mineral soil (0 to 25 cm depth)

Properties of only the upper mineral soil are shown in tables 7.1, 7.2, and 8.1. Differences in mineral soil among zones across the gradient are less frequently statistically significant than either those for the forest floor or those for the total mean-weighted forest floor and upper mineral soil combined; however, the trends across the gradient are similar (table 7.1). The differences in mineral soil properties among forest types are consistent with the patterns for forest floor and the mean-weighted forest floor plus upper mineral soil (tables 7.2 and 8.1).

Mineral soil (25 to 100 cm depth)

Properties of the deeper mineral soil are presented by 25 cm depths to 100 cm in tables 9 through 14. The patterns among zones across the deposition gradient, among forest types, and among individual types across the gradient as described for the forest floor and the surface mineral soil are consistently repeated for depths to 100 cm (tables 9 through 14). Changes occur with depth as expected; for example, base saturation, pH, cation exchange capacity, and exchangeable base cations increase and exchangeable acidity decreases with depth, and the changes with depth are consistent among the zones across the gradient.

Tree wood tissue

Tables 15 through 18 show the growth, ash content, and elemental concentrations for three 10-year increments of wood tissue, 1976-1985, 1966-1975, and 1956-1965 by forest type across the zones of the sulfate deposition gradient. Length of the growth increment and its ash content are not significantly different among zones across the gradient (tables 15.1, 16.1, and 17.1), but are significantly different among forest types (tables 15.2, 16.2, and 17.2). Both are also different among growth periods (shown in table 18, but not tested statistically). Many of the differences in elemental concentrations are significant across the zones of the gradient, but the trends often show little pattern (Al, Cr, Fe, Ni, Na). A few elements do show a trend; for example, Mn concentrations increase and N and P concentrations decrease across the gradient. There is also a pattern of increase in concentration of some elements from the outer (most recent) growth increment to the oldest inner increment (Ca, Mg, and Mn) and a decrease in others (P, Na, Ni). These patterns are most evident in table 18, where means are displayed for each increment by each forest type across the zones of the gradient. This pattern has also been reported by Tendel and Wolf (1988), using four decades of pine wood tissue. They described one group of elements that decreased in concentration from older to younger wood (Ca, Mg, Mn, Zn, Al, Pb, and Cd) and a second group that increased in concentration (K, P, S, Fe, Cu, and N). They attributed the changes in concentrations to increased deposition of certain elements and the progressive leaching of other elements by sulfur-dioxide, although "natural" elemental translocation within woody tissue should not be disregarded (Kohno *et al.* 1988, Lovestam *et al.* 1990). In our study, for those elements reported by Tendel and Wolf (1988) to decrease in

concentration from older to younger wood, only Al and Pb do not follow the pattern; their concentrations are opposite in direction. For elements reported to increase in concentration from older to younger wood, only K follows the opposite pattern. When we consider concentrations only within pine, Al and Pb still do not conform to the pattern described by Tendel and Wolf (1988), but K does conform to the pattern. The failure of concentrations of Al and Pb in our study to conform to the patterns found in pine wood in Germany may be due to the differences in cumulative acid sulfate influence in the two countries.

Ratios of elements can also be examined in tree wood tissue. Patterns of ratios can be enlightning. For example, Ohmann and Grigal (1990) showed an association of S to N molar ratios in the most recent decade of wood tissue with that of S to N ratios in the soil and of sulfate deposition as represented by the zones across the gradient. Elemental ratios can also be examined by way of the Diagnosis and Recommendation Integrated System (DRIS) (Beaufils 1973). Although designed to develop indices of plant nutritional status from foliar nutrient analyses in agronomic applications, this system has been used in forestry applications (Riitters 1990). DRIS was used to describe the variation of 12 elements in tree wood tissue of the five species in this study (Riitters *et al.* In press). It indicated that the older wood of most species was relatively depleted of N, P, K, S, Fe, Cu, and Al; and relatively enriched in Ca, Mg, Mn, B, and Zn. Sulfur in the older wood was relatively less depleted from west to east across the deposition gradient; the trend was most apparent for hardwood species (Riitters *et al.* In press).

ACKNOWLEDGMENTS

Funding was provided by the USDA Forest Service Forest Response Program, National Vegetation Survey, under the National Acid Precipitation Assessment Program, and by the Minnesota Agriculture Experiment Station under project 25-54. This paper is published as No. 18731 of the scientific journal series of that station. We thank the many people who assisted in the sample collection and in the many chemical analyses.

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Table 1.1.—*Properties of the total mean-weighted forest floor and upper mineral soil of 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Property[1]	Zone[2]					Anova[3]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
BSAT	94 a[4]	85 a	74 b	55 c	66 b	19.8	0.00	1.460
	(22)	(31)	(39)	(41)	(34)			
C	21 a	26 ab	30 b	22 a	25 ab	2.4	.05	.099
	(23)	(31)	(39)	(42)	(34)			
CEC	10.0 a	8.9 ab	6.9 bc	5.8 c	6.2 c	3.5	.01	.396
	(23)	(31)	(39)	(41)	(34)			
Ca	8.0 a	6.1 ab	4.2 bc	2.8 c	4.3 bc	6.5	.00	.327
Mg	1.3 ab	1.4 a	1.1 ab	.7 b	.9 ab	2.2	.07	.095
K	.31 a	.28 ab	.23 b	.16 c	.11 c	11.1	.00	.010
Na	.03	.06	.06	.04	.05	1.4	.23	.004
LOI	40 a	48 ab	54 b	42 a	46 ab	2.2	.07	.175
	(23)	(31)	(39)	(42)	(34)			
N	1.2	1.3	1.4	1.1	1.1	1.9	.11	.005
pH	5.5 a	4.8 b	4.5 c	4.4 c	4.7 bc	12.6	.00	.049
	(23)	(31)	(39)	(40)	(34)			
S	.16	.17	.18	.16	.17	.7	.59	.001
	(23)	(31)	(39)	(42)	(34)			

[1] BSAT = percent base saturation [(Ca + Mg + K + Na) / CEC] * 100; CEC = cation exchange capacity (Ac + Ca + Mg + K + Na), and exchangeable cations - calcium, magnesium, potassium, and sodium (cmol (+) kg^{-1}); LOI = loss on ignition, carbon, nitrogen, sulfur (g kg^{-1}); pH in 0.01 *M* $CaCl_2$.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 1.2.—*Properties of the total mean-weighted forest floor and upper mineral soil of 169 plots by forest type across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Property[1]	Forest Type[2]					Anova[3]		
	Bf	Sm	Jp	Rp	A	F	P	$MSE^{0.5}$
BSAT	76 a[4]	79 a	63 b	61 b	81 a	7.9	0.00	1.460
	(24)	(39)	(39)	(27)	(38)			
C	45 a	28 b	16 c	15 c	26 b	24.6	.00	.099
	(24)	(41)	(39)	(27)	(38)			
CEC	11.2 a	8.5 b	3.5 c	3.1 c	10.3 ab	17.1	.00	.396
	(24)	(40)	(39)	(27)	(38)			
Ca	6.9 a	6.0 a	1.9 b	1.6 b	7.1 a	13.0	.00	.327
Mg	2.0 a	1.0 b	.4 c	.3 c	1.7 a	11.9	.00	.095
K	.25 a	.26 a	.12 b	.11 b	.29 a	11.6	.00	.010
Na	.07 a	.04 b	.04 b	.04 b	.06 a	2.4	.05	.004
LOI	32 a	52 b	29 c	28 c	50 b	25.7	.00	.175
	(24)	(41)	(39)	(27)	(38)			
N	2.0 a	1.5 b	.7 c	.7 c	1.5 b	25.1	.00	.005
pH	4.8 a	4.9 a	4.4 b	4.4 b	5.0 a	6.8	.00	.049
	(24)	(40)	(39)	(27)	(37)			
S	.25 a	.20 b	.10 c	.10 c	.19 b	21.0	.00	.001
	(24)	(41)	(39)	(27)	(38)			

[1] BSAT = percent base saturation [(Ca + Mg + K + Na) / CEC] * 100; CEC = cation exchange capacity (Ac + Ca + Mg + K + Na), and exchangeable cations - calcium, magnesium, potassium, and sodium (cmol (+) kg^{-1}); LOI = loss on ignition, carbon, nitrogen, sulfur (g kg^{-1}); pH in 0.01 *M* $CaCl_2$.

[2] Forest type: Bf = Balsam fir, Sm = Sugar maple, Jp = Jack pine, Rp = Red pine, A = Aspen.

[3] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 2.1.—*Properties of the total mean-weighted forest floor and upper mineral soil of five forest types across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Forest type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	MSE$^{0.5}$
				Base Saturation (percent)[3]				
Balsam fir	77	66	70	71	97	2.1	0.12	4
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	99 a[4]	92 ab	81 bc	55 d	73 c	11.0	.00	3
	(8)	(8)	(8)	(8)	(8)			
Jack pine	91 a	80 ab	70 b	41 c	34 c	22.9	.00	2
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	80	61	52	61	1.2	.32	5
	—	(4)	(8)	(8)	(7)			
Aspen	96 a	96 a	85 a	55 b	80 a	8.4	.00	3
	(6)	(8)	(9)	(9)	(6)			
				Carbon (g kg^{-1})				
Balsam fir	19	35	60	32	61	2.2	0.11	0.491
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	24 a	29 a	42 b	24 a	20 a	4.0	.01	.182
	(8)	(8)	(8)	(9)	(8)			
Jack pine	19 ab	21 a	11 c	13 c	15 bc	5.0	.00	.081
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	14	14	17	15	.8	.50	.078
	—	(4)	(8)	(8)	(7)			
Aspen	21	29	29	24	28	1.0	.44	.145
	(6)	(8)	(9)	(9)	(6)			
				Cation Exchange Capacity (cmol(+) kg^{-1})[3]				
Balsam fir	5.0	11.5	10.6	8.6	17.2	1.4	0.27	1.436
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	14.1 a	9.1 b	9.0 bc	6.6 bc	4.6 c	4.9	.00	.698
	(8)	(8)	(8)	(8)	(8)			
Jack pine	5.4 a	5.1 a	2.8 b	2.3 b	2.0 b	13.8	.00	.194
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	3.7	2.9	3.6	2.4	1.2	.34	.265
	—	(4)	(8)	(8)	(7)			
Aspen	12.2	13.2	9.9	7.6	9.1	.7	.59	1.241
	(6)	(8)	(9)	(9)	(6)			
				Exchangeable Calcium (cmol(+) kg^{-1})				
Balsam fir	3.0	5.8	5.8	5.0	13.0	2.1	0.12	1.101
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	10.9 a	7.0 b	6.2 bc	2.7 c	3.2 c	6.5	.00	.578
	(8)	(8)	(8)	(8)	(8)			
Jack pine	4.0 a	3.1 a	1.5 b	.6 bc	.4 c	24.3	.00	.142
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	2.4	1.4	1.9	1.3	.7	.56	.263
	—	(4)	(8)	(8)	(7)			
Aspen	10.1	10.0	6.2	3.4	7.0	1.6	.19	1.021
	(6)	(8)	(9)	(9)	(6)			

(Table 2.1 continued on next page)

(Table 2.1 continued)

Forest type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
				Exchangeable Magnesium (cmol(+) kg^{-1})				
Balsam fir	0.6	2.6	1.3	1.4	3.6	1.0	0.42	0.473
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	1.8 a	1.1 bc	1.1 b	.5 cd	.4 d	7.2	.00	.096
	(8)	(8)	(8)	(8)	(8)			
Jack pine	.8 a	.6 a	.3 b	.2 c	.1 c	27.0	.00	.026
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	.4	.3	.2	.2	.8	.52	.037
	—	(4)	(8)	(8)	(7)			
Aspen	1.5	2.4	2.2	1.1	1.1	1.1	.37	.270
	(6)	(8)	(9)	(9)	(6)			
				Exchangeable Potassium (cmol(+) kg^{-1})				
Balsam fir	0.25 ab	0.38 a	0.31 ab	0.18 b	0.19 b	2.4	0.09	0.026
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	.44 a	.28 b	.26 b	.17 bc	.09 c	9.7	.00	.021
	(8)	(8)	(8)	(8)	(8)			
Jack pine	.18 a	.20 a	.10 b	.08 b	.07b	14.8	.00	.007
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	.17 a	.10 b	.11 b	.08 b	3.3	.04	.009
	—	(4)	(8)	(8)	(7)			
Aspen	.27	.38	.38	.24	.14	1.8	.16	.033
	(6)	(8)	(9)	(9)	(6)			
				Exchangeable Sodium (cmol(+) kg^{-1})				
Balsam fir	0.008	0.074	0.054	0.053	0.123	1.3	0.32	0.013
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	.030	.030	.036	.049	.063	.8	.51	.007
	(8)	(8)	(8)	(8)	(8)			
Jack pine	.019	.039	.028	.041	.049	.5	.76	.008
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	.072 a	.044 ab	.058 a	.010 b	2.4	.09	.008
	—	(4)	(8)	(8)	(7)			
Aspen	.060 ab	.082 ab	.108 a	.030 b	.027 b	3.3	.03	.009
	(6)	(8)	(9)	(9)	(6)			
				Loss On Ignition (g kg^{-1})				
Balsam fir	34	64	106	60	111	2.2	0.10	0.841
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	46 a	53 a	76 b	46 a	38 a	3.8	.01	.328
	(8)	(9)	(8)	(8)	(8)			
Jack pine	34 ab	38 a	21 c	25 c	28 bc	4.5	.01	.149
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	27	26	32	27	1.0	.43	.147
	—	(4)	(8)	(8)	(7)			
Aspen	40	54	54	46	52	1.0	.43	.280
	(6)	(8)	(9)	(9)	(6)			

(Table 2.1 continued on next page)

(Table 2.1 continued)

Forest type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
				Nitrogen (g kg^{-1})				
Balsam fir	0.8	1.6	2.6	1.5	2.6	1.7	0.20	0.022
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	1.6 ab	1.6 ab	2.1 a	1.4 b	1.1 b	2.3	.07	.011
	(8)	(8)	(8)	(9)	(8)			
Jack pine	.8 ab	.9 a	.6 b	.6 b	.6 b	3.9	.01	.003
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	.7	.6	.7	.6	.8	.51	.004
	—	(4)	(8)	(8)	(7)			
Aspen	1.3	1.7	1.6	1.3	1.4	.6	.68	.009
	(6)	(8)	(9)	(9)	(6)			
				pH ($CaCl_2$)[3]				
Balsam fir	4.5 a	4.3 a	4.4 a	4.7 a	6.1 b	6.8	0.00	0.126
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	5.9 a	5.1 b	4.7 bc	4.3 c	4.5 bc	8.9	.00	.096
	(8)	(8)	(8)	(8)	(8)			
Jack pine	4.9 a	4.6 ab	4.5 bc	4.2 cd	3.9 d	11.9	.00	.050
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	4.6	4.4	4.4	4.4	.3	.80	.077
	—	(4)	(8)	(8)	(7)			
Aspen	5.9 a	5.2 ab	4.7 bc	4.4 c	5.0 bc	4.5	.01	.120
	(6)	(8)	(9)	(8)	(6)			
				Sulfur (g kg^{-1})				
Balsam fir	0.11	0.18	0.31	0.22	0.35	1.7	0.19	0.003
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	.21	.21	.26	.18	.16	1.5	.24	.001
	(8)	(8)	(8)	(9)	(8)			
Jack pine	.10	.12	.09	.10	.10	1.6	.20	.001
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	.10	.09	.11	.09	1.3	.31	.001
	—	(4)	(8)	(8)	(7)			
Aspen	.17	.21	.18	.19	.23	.4	.79	.002
	(6)	(8)	(9)	(9)	(6)			

[1] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[2] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[3] Base Saturation = [(Ca + Mg + K + Na) / CEC] * 100; Cation Exchange Capacity = (Ac + Ca + Mg + K + Na); pH in 0.01 *M* $CaCl_2$.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

(Table 2.1 continued)

Forest type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
				Exchangeable Magnesium (cmol(+) kg^{-1})				
Balsam fir	0.6	2.6	1.3	1.4	3.6	1.0	0.42	0.473
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	1.8 a	1.1 bc	1.1 b	.5 cd	.4 d	7.2	.00	.096
	(8)	(8)	(8)	(8)	(8)			
Jack pine	.8 a	.6 a	.3 b	.2 c	.1 c	27.0	.00	.026
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	.4	.3	.2	.2	.8	.52	.037
	—	(4)	(8)	(8)	(7)			
Aspen	1.5	2.4	2.2	1.1	1.1	1.1	.37	.270
	(6)	(8)	(9)	(9)	(6)			
				Exchangeable Potassium (cmol(+) kg^{-1})				
Balsam fir	0.25 ab	0.38 a	0.31 ab	0.18 b	0.19 b	2.4	0.09	0.026
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	.44 a	.28 b	.26 b	.17 bc	.09 c	9.7	.00	.021
	(8)	(8)	(8)	(8)	(8)			
Jack pine	.18 a	.20 a	.10 b	.08 b	.07b	14.8	.00	.007
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	.17 a	.10 b	.11 b	.08 b	3.3	.04	.009
	—	(4)	(8)	(8)	(7)			
Aspen	.27	.38	.38	.24	.14	1.8	.16	.033
	(6)	(8)	(9)	(9)	(6)			
				Exchangeable Sodium (cmol(+) kg^{-1})				
Balsam fir	0.008	0.074	0.054	0.053	0.123	1.3	0.32	0.013
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	.030	.030	.036	.049	.063	.8	.51	.007
	(8)	(8)	(8)	(8)	(8)			
Jack pine	.019	.039	.028	.041	.049	.5	.76	.008
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	.072 a	.044 ab	.058 a	.010 b	2.4	.09	.008
	—	(4)	(8)	(8)	(7)			
Aspen	.060 ab	.082 ab	.108 a	.030 b	.027 b	3.3	.03	.009
	(6)	(8)	(9)	(9)	(6)			
				Loss On Ignition (g kg^{-1})				
Balsam fir	34	64	106	60	111	2.2	0.10	0.841
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	46 a	53 a	76 b	46 a	38 a	3.8	.01	.328
	(8)	(9)	(8)	(8)	(8)			
Jack pine	34 ab	38 a	21 c	25 c	28 bc	4.5	.01	.149
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	27	26	32	27	1.0	.43	.147
	—	(4)	(8)	(8)	(7)			
Aspen	40	54	54	46	52	1.0	.43	.280
	(6)	(8)	(9)	(9)	(6)			

(Table 2.1 continued on next page)

(Table 2.1 continued)

Forest type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
				Nitrogen (g kg^{-1})				
Balsam fir	0.8	1.6	2.6	1.5	2.6	1.7	0.20	0.022
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	1.6 ab	1.6 ab	2.1 a	1.4 b	1.1 b	2.3	.07	.011
	(8)	(8)	(8)	(9)	(8)			
Jack pine	.8 ab	.9 a	.6 b	.6 b	.6 b	3.9	.01	.003
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	.7	.6	.7	.6	.8	.51	.004
	—	(4)	(8)	(8)	(7)			
Aspen	1.3	1.7	1.6	1.3	1.4	.6	.68	.009
	(6)	(8)	(9)	(9)	(6)			
				pH ($CaCl_2$)[3]				
Balsam fir	4.5 a	4.3 a	4.4 a	4.7 a	6.1 b	6.8	0.00	0.126
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	5.9 a	5.1 b	4.7 bc	4.3 c	4.5 bc	8.9	.00	.096
	(8)	(8)	(8)	(8)	(8)			
Jack pine	4.9 a	4.6 ab	4.5 bc	4.2 cd	3.9 d	11.9	.00	.050
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	4.6	4.4	4.4	4.4	.3	.80	.077
	—	(4)	(8)	(8)	(7)			
Aspen	5.9 a	5.2 ab	4.7 bc	4.4 c	5.0 bc	4.5	.01	.120
	(6)	(8)	(9)	(8)	(6)			
				Sulfur (g kg^{-1})				
Balsam fir	0.11	0.18	0.31	0.22	0.35	1.7	0.19	0.003
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	.21	.21	.26	.18	.16	1.5	.24	.001
	(8)	(8)	(8)	(9)	(8)			
Jack pine	.10	.12	.09	.10	.10	1.6	.20	.001
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	.10	.09	.11	.09	1.3	.31	.001
	—	(4)	(8)	(8)	(7)			
Aspen	.17	.21	.18	.19	.23	.4	.79	.002
	(6)	(8)	(9)	(9)	(6)			

[1] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[2] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[3] Base Saturation = [(Ca + Mg + K + Na) / CEC] * 100; Cation Exchange Capacity = (Ac + Ca + Mg + K + Na); pH in 0.01 *M* $CaCl_2$.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 3.1.—*Properties of the forest floor of 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Property[1]	Zone[2]					Anova[3]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
BSAT	100 a[4]	98 a	96 b	94 c	92 d	13.0	0.00	0.363
	(22)	(31)	(39)	(41)	(34)			
BD	.14 ab	.29 c	.23 bc	.10 a	.14 ab	5.4	.00	.015
	(23)	(31)	(39)	(42)	(34)			
CEC	54.3 a	38.6 b	33.4 bc	33.9 bc	31.3 c	9.3	.00	1.099
	(22)	(31)	(39)	(41)	(34)			
Ca	43.7 a	31.1 b	25.8 bc	26.0 bc	24.5 c	9.4	.00	.937
	(23)	(31)	(39)	(41)	(34)			
Mg	7.2 a	5.3 b	5.0 bc	4.5 bc	4.0 c	6.1	.00	.192
K	2.01 a	1.61 b	1.50 b	1.65 b	1.21 c	5.5	.00	.046
Na	.14	.16	.10	.11	.09	1.9	.11	.009
LOI	500 ab	450 a	520 b	640 c	550 b	7.7	.00	1.140
	(23)	(31)	(39)	(42)	(34)			
N	10.6 abc	9.1 a	9.8 ab	12.2 c	10.8 bc	5.1	.00	.025
	(23)	(31)	(39)	(42)	(34)			
pH	5.8 a	5.4 b	4.9 c	4.6 d	4.6 d	26.7	.00	.043
	(23)	(31)	(39)	(40)	(34)			
S	1.1 a	1.0 a	1.0 a	1.4 b	1.4 b	9.0	.00	.003
	(23)	(31)	(39)	(42)	(34)			

[1] BSAT = percent base saturation [(Ca + Mg + K + Na) / CEC] * 100; BD = bulk density (Mg m^{-3}); CEC = cation exchange capacity (Ac + Ca + Mg + K + Na), and exchangeable cations - calcium, magnesium, potassium, and sodium (cmol (+) kg^{-1}); LOI = loss on ignition, nitrogen, and sulfur (g kg^{-1}); pH in 0.01 *M* $CaCl_2$.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 3.2.—*Property of the forest floor of 169 plots by five forest types across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Property[1]	Forest type[2]					Anova[3]		
	Bf	Sm	Jp	Rp	A	F	P	$MSE^{0.5}$
BSAT	98 a[4]	98 a	91 b	92 b	98 a	20.3	0.00	0.363
	(24)	(39)	(39)	(27)	(38)			
BD	.20 ab	.28 a	.11 b	.13 b	.16 b	4.4	.00	.015
	(24)	(41)	(39)	(27)	(38)			
CEC	43.2 ab	41.0 a	26.3 c	22.1 c	49.8 b	21.2	.00	1.099
	(24)	(39)	(39)	(27)	(38)			
Ca	34.7 ab	33.8 a	19.2 c	15.8 c	39.9 b	23.2	.00	.937
	(24)	(40)	(39)	(27)	(38)			
Mg	5.7 a	4.7 ab	3.9 bc	3.4 c	7.4 d	13.4	.00	.192
K	1.8 ab	1.6 bc	1.4 cd	1.1 d	1.9 a	7.7	.00	.046
Na	.13 ab	.10 b	.07 b	.10 b	.18 a	4.3	.00	.009
LOI	610 a	470 b	580 ac	580 ac	520 bc	4.3	.00	1.140
	(24)	(41)	(39)	(27)	(38)			
N	12.0 a	10.5 a	10.7 a	8.50 b	11.3 a	4.6	.00	.025
	(24)	(41)	(39)	(27)	(38)			
pH	5.1 a	5.4 a	4.4 b	4.4 b	5.6 c	34.1	.00	.043
	(24)	(40)	(39)	(27)	(37)			
S	1.4 a	1.2 b	1.2 b	.9 c	1.3 ab	6.5	.00	.003
	(24)	(41)	(39)	(27)	(38)			

[1] BSAT = percent base saturation [(Ca + Mg + K + Na) / CEC] * 100; BD = bulk density ($Mg\ m^{-3}$); CEC = cation exchange capacity (Ac + Ca + Mg + K + Na), and exchangeable cations - calcium, magnesium, potassium, and sodium ($cmol\ (+)\ kg^{-1}$); LOI = loss on ignition, nitrogen, and sulfur ($g\ kg^{-1}$); pH in 0.01 *M* $CaCl_2$.

[2] Forest type: Bf = Balsam fir, Sm = Sugar maple, Jp = Jack pine, Rp = Red pine, A = Aspen.

[3] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 4.1.—*Properties of the forest floor of 169 plots for five forest types by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Forest type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
				Base Saturation (percent)[3]				
Balsam fir	100	97	98	97	99	0.5	0.76	0.632
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	100 a[4]	99 a	98 ab	96 bc	96 c	5.6	.00	.341
	(7)	(8)	(8)	(8)	(8)			
Jack pine	97 a	98 a	94 a	89 b	77 c	24.5	.00	.788
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	96	92	91	92	1.4	.28	.804
	—	(4)	(8)	(8)	(7)			
Aspen	100 a	100 a	99 a	95 b	99 ab	2.5	.06	.549
	(6)	(8)	(9)	(9)	(6)			
				Bulk Density (Mg m^{-3})				
Balsam fir	0.17 ab	0.14 b	0.40 a	0.13 b	0.13 b	2.7	0.06	0.035
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	.13 a	.66 b	.37 ab	.11 a	.15 a	5.4	.00	.045
	(8)	(8)	(8)	(9)	(8)			
Jack pine	.15 a	.14 ab	.06 c	.10 bc	.12 ab	6.1	.00	.006
	(8)	(8)	(8)	(7)	(8)			
Red pine	—	.27 a	.10 b	.07 b	.14 b	4.6	.01	.018
	—	(4)	(8)	(8)	(7)			
Aspen	.13	.14	.26	.09	.16	1.2	.32	.028
	(6)	(8)	(9)	(9)	(6)			
				Cation Exchange Capacity (cmol (+) kg^{-1})[3]				
Balsam fir	56.5	39.1	34.9	41.3	56.7	1.6	0.23	3.266
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	55.6 a	40.9 ab	36.1 b	37.5 b	36.5 b	2.2	.09	2.385
	(7)	(8)	(8)	(8)	(8)			
Jack pine	34.2 a	32.1 a	30.3 a	21.4 b	14.4 b	7.8	.00	1.342
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	20.7 ab	21.3 ab	28.6 a	16.2 b	3.4	.03	1.456
	—	(4)	(8)	(8)	(7)			
Aspen	79.1 a	50.9 b	43.5 b	39.9 b	43.3 b	5.4	.00	2.859
	(6)	(8)	(9)	(9)	(6)			
				Exchangeable Calcium (cmol (+) kg^{-1})				
Balsam fir	47.6	30.1	28.6	33.1	45.8	1.5	0.24	2.800
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	42.9	35.4	29.5	30.6	30.4	1.4	.24	2.093
	(8)	(8)	(8)	(8)	(8)			
Jack pine	26.8 a	25.3 a	22.0 a	14.6 b	7.9 b	10.1	.00	1.117
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	15.6	14.9	20.5	11.8	2.3	.10	1.262
	—	(4)	(8)	(8)	(7)			
Aspen	66.7 a	40.2 b	33.9 b	30.6 b	35.7 b	6.8	.00	2.320
	(6)	(8)	(9)	(9)	(6)			

(Table 4.1 continued on next page)

(Table 4.1 continued)

Forest type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
				Exchangeable Magnesium (cmol (+) kg^{-1})				
Balsam fir	7.0	5.6	4.0	5.2	8.4	2.2	0.11	0.520
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	7.5 a	4.0 b	4.5 b	3.9 b	3.5 b	6.6	.00	.283
	(8)	(8)	(8)	(8)	(8)			
Jack pine	5.1 a	4.6 a	5.0 a	3.1 b	1.7 c	9.8	.00	.213
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	3.2 ab	3.5 ab	4.4 b	2.3 a	4.2	.02	.219
	—	(4)	(8)	(8)	(7)			
Aspen	9.8	8.3	7.5	5.7	5.9	1.3	.29	.632
	(6)	(8)	(9)	(9)	(6)			
				Exchangeable Potassium (cmol (+) kg^{-1})				
Balsam fir	1.8	2.3	1.6	1.7	1.7	0.8	0.56	0.145
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	2.3 a	1.2 b	1.6 b	1.6 b	1.2 b	4.0	.01	.106
	(8)	(8)	(8)	(8)	(8)			
Jack pine	1.5	1.5	1.5	1.4	1.2	.5	.70	.070
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	1.1 ab	1.1 ab	1.4 a	.9 b	2.6	.08	.079
	—	(4)	(8)	(8)	(7)			
Aspen	2.4 a	2.1 a	1.7 ab	2.1 a	1.3 b	2.3	.08	.109
	(6)	(8)	(9)	(9)	(6)			
				Exchangeable Sodium (cmol (+) kg^{-1})				
Balsam fir	0.04	0.13	0.09	0.15	0.18	0.5	0.75	0.023
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	.13 ab	.16 a	.05 c	.07 bc	.09 abc	3.2	.02	.011
	(8)	(8)	(8)	(8)	(8)			
Jack pine	.07	.06	.04	.08	.11	.6	.66	.015
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	.12	.11	.12	.04	1.0	.42	.019
	—	(4)	(8)	(8)	(7)			
Aspen	.27 a	.28 a	.19 ab	.11 ab	.04 b	2.5	.06	.028
	(6)	(8)	(9)	(9)	(6)			
				Loss On Ignition (g kg^{-1})				
Balsam fir	470	590	510	610	760	1.4	0.28	3.803
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	440 ab	330 a	460 ab	570 b	500 b	3.3	.02	2.211
	(8)	(8)	(8)	(9)	(8)			
Jack pine	500 a	510 ab	620 c	650 c	610 bc	3.3	.02	1.674
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	390 a	600 b	780 c	440 a	11.4	.00	2.577
	—	(4)	(7)	(8)	(8)			
Aspen	590 ab	480 bc	440 c	620 a	470 bc	2.8	.04	2.203
	(6)	(8)	(9)	(9)	(6)			

(Table 4.1 continued on next page)

(Table 4.1 continued)

Forest type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
				Nitrogen (g kg^{-1})				
Balsam fir	12.2	10.6	10.2	12.5	14.5	0.9	0.49	0.084
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	8.4 a	8.1 a	9.6 ab	13.1 b	12.7 b	3.5	.02	.057
	(8)	(8)	(8)	(9)	(8)			
Jack pine	9.8 a	10.4 ab	12.0 b	11.5 ab	9.8 a	2.6	.06	.028
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	6.2 a	8.1 a	11.2 b	7.2 a	8.3	.00	.037
	—	(4)	(8)	(8)	(7)			
Aspen	14.5 a	9.7 bc	9.3 c	12.7 ab	10.9 ab	2.8	.04	.056
	(6)	(8)	(9)	(9)	(6)			
				pH ($CaCl_2$)[3]				
Balsam fir	6.0	4.9	4.9	5.1	5.2	1.0	0.46	0.120
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	6.2 a	5.8 a	5.1 b	4.7 b	4.9 b	9.5	.00	.094
	(8)	(8)	(8)	(8)	(8)			
Jack pine	4.9 a	4.9 a	4.5 a	4.0 b	3.4 c	17.3	.00	.068
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	4.7	4.4	4.2	4.4	.8	.50	.089
	—	(4)	(8)	(8)	(7)			
Aspen	6.6 a	6.0 b	5.7 b	4.8 c	5.4 bc	10.2	.00	.087
	(8)	(6)	(9)	(8)	(6)			
				Sulfur (g kg^{-1})				
Balsam fir	1.3	1.2	1.1	1.5	1.9	1.7	0.20	0.011
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	.9 a	1.0 a	1.0 a	1.4 b	1.5 b	4.2	.01	.006
	(8)	(8)	(8)	(9)	(8)			
Jack pine	1.0 a	1.1 a	1.2 ab	1.3 b	1.2 ab	2.4	.07	.004
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	.6 a	.8 ab	1.2 c	.9 b	10.3	.00	.004
	—	(4)	(8)	(8)	(7)			
Aspen	1.6 a	1.0 b	1.0 b	1.5 ab	1.5 ab	2.8	.04	.008
	(6)	(8)	(9)	(9)	(6)			

[1] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[2] ANOVA: F = F value, P = probability, $MSE^{0.50}$ = square root of mean square error.

[3] Base Saturation = [(Ca + Mg + K + Na) / CEC] * 100; Cation Exchange Capacity = (Ac + Ca + Mg + K + Na); pH in 0.01 *M* $CaCl_2$.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 5.1.—*Ash and carbon content (g kg^{-1}) and total elemental chemical concentrations (mg kg^{-1}) of the forest floor of 169 plots by zone across a Lake States sulfate deposition gradient*

Element	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
Ash	48 ab[3]	54 a	46 b	35 c	45 b	7.9	0.00	1.128
Aluminum	4,980 a	5,210 a	3,970 b	3,550 bc	3,100 c	10.6	.00	111
Boron	19.2 a	12.3 bc	13.0 b	10.3 c	10.4 bc	9.4	.00	.441
Calcium	1,530 a	9,750 b	8,150 bc	7,830 c	8,000 bc	16.0	.00	308
Cadmium	1.0	1.0	1.1	1.2	1.2	1.5	.20	.044
Carbon	31 ab	28 a	32 b	38 c	33 b	7.3	.00	.621
Chromium	10 a	12 a	11 a	8 b	7 b	10.8	.00	.289
Copper	7.5	6.9	8.1	8.9	7.9	1.7	.14	.302
Iron	5,490 a	7,270 b	7,460 b	4,620 ac	3,650 c	12.8	.00	208
Lead	33 a	45 b	42 ab	58 c	72 d	17.0	.00	1.591
Magnesium	2,080 a	1,860 a	1,990 a	1,200 b	1,060 b	12.4	.00	56
Manganese	1,300 abc	1,640 a	1,270 bc	1,460 ab	970 c	3.4	.01	58
Nickel	11 a	13 a	13 a	9 b	7 b	9.0	.00	.383
Phosphorus	934 a	849 ab	816 b	872 ab	708 c	4.1	.00	15
Potassium	1,360 a	1,340 b	1,070 b	1,010 b	790 c	10.1	.00	24
Sodium	105 a	126 b	97 a	75 c	59 d	16.3	.00	2.702
Zinc	107	122	106	120	101	1.1	.37	3.429
No. plots	(23)	(31)	(39)	(42)	(34)			

[1] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[2] ANOVA: F = F value, P= probability, $MSE^{0.5}$ = square root of mean square error.

[3] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 5.2.—*Ash and carbon content (g kg^{-1}) and total elemental chemical concentrations (mg kg^{-1}) of the forest floor of 169 plots by forest type across a Lake States sulfate deposition gradient*

Element	Forest type[1]					Anova[2]		
	Bf	Sm	Jp	Rp	A	F	P	MSE$^{0.5}$
Ash	39 a[3]	52 b	41 c	40 ac	47 bc	4.1	0.00	1.128
Aluminum	4,280 a	4,310 a	3,980 a	2,950 b	4,490 a	3.6	0.01	111
Boron	13.5 a	15.1 a	9.5 b	8.3 b	15.2 a	9.5	.00	.441
Calcium	10,060 a	11,160 a	5,970 b	5,440 b	13,270 c	22.8	.00	308
Cadmium	1.2 a	1.3 a	.9 b	.8 b	1.4 a	7.0	.00	.044
Carbon	36 a	29 b	35 ac	35 ac	32 bc	4.2	.00	.621
Chromium	10 a	11 a	7 b	7 b	11 a	8.3	.00	.289
Copper	8.9 a	9.6 a	6.1 b	5.5 b	9.2 a	8.4	.00	.302
Iron	7,200 a	6,260 a	4,540 b	3,410 b	6,900 a	10.2	.00	208
Lead	61 a	47 b	65 a	45 b	42 b	8.9	.00	1.591
Magnesium	1,780 a	1,610 a	1,180 b	920 b	2,370 c	18.3	.00	56
Manganese	1,550 ab	1,720 a	1,110 c	1,020 c	1,200 bc	5.3	.00	58
Nickel	11 ab	11 ab	8 c	9 ac	13 b	5.5	.00	.383
Phosphorus	868 a	882 a	784 b	634 c	974 d	13.5	.00	15
Potassium	1,070 ab	1,100 a	960 b	750 c	1,280 d	10.6	.00	24
Sodium	106 a	98 a	78 b	57 c	108 a	9.6	.00	2.702
Zinc	142 a	114 b	88 c	69 c	144 a	16.3	.00	3.429
No. plots	(24)	(41)	(39)	(27)	(38)			

[1] Forest type: Bf = Balsam fir, Sm = Sugar maple, Jp = Jack pine, Rp = Red pine, A = Aspen.

[2] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[3] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 6.1—*Ash and carbon content (g kg^{-1}) and total elemental chemical concentrations (mg kg^{-1}) of the forest floor of 169 plots for five forest types across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Forest type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	MSE$^{0.5}$
				Ash Content				
Balsam fir	49	42	48	38	25	1.2	0.33	3.774
	(1)	(4)	(6)	(8)	(5)			
Sugar maple	53 ab[3]	66 b	52 ab	42 a	48 a	3.3	.02	2.266
	(8)	(8)	(8)	(9)	(8)			
Jack pine	48 a	49 a	37 b	34 b	40 ab	3.2	.02	1.670
	(8)	(7)	(8)	(8)	(8)			
Red pine	—	58 a	38 b	22 c	55 a	11.5	.00	2.454
	—	(4)	(7)	(8)	(8)			
Aspen	40 ab	52 bc	56 ac	37 a	52 bc	3.1	.03	2.193
	(6)	(8)	(9)	(9)	(6)			
				Aluminum				
Balsam fir	5,730	4,590	4,850	3,940	3,630	0.5	0.71	379
Sugar maple	4,900 ab	5,840 a	3,570 bc	4,080 bc	3,200 c	5.2	.00	207
Jack pine	4,870 a	5,200 a	3,880 b	3,220 bc	2,880 c	8.5	.00	153
Red pine	—	3,990 a	3,250 ab	2,660 bc	2,350 c	4.1	.02	158
Aspen	5,100	5,500	4,460	3,760	3,680	1.1	.38	341
				Boron				
Balsam fir	24.3 a	8.6 b	19.2 a	10.0 b	14.1 ab	2.7	0.06	1.410
Sugar maple	23.8 a	16.2 b	13.8 b	11.0 b	11.3 b	7.5	.00	.860
Jack pine	11.0	10.9	10.0	8.6	7.1	1.2	.36	.700
Red pine	—	9.3	9.1	8.0	7.3	.5	.69	.640
Aspen	23.2 a	12.8 b	14.3 b	13.5 b	14.4 b	2.4	.07	1.140
				Calcium				
Balsam fir	16,640 a	7,870 b	8,200 b	8,740 b	14,830 a	3.9	0.02	752
Sugar maple	17,640 a	10,620 b	9,360 b	8,750 b	9,710 b	6.5	.00	636
Jack pine	7,740 a	7,970 a	6,920 ab	5,020 b	2,450 c	8.6	.00	351
Red pine	—	5,190	5,270	6,800	4,210	1.7	.20	434
Aspen	23,680 a	13,670 b	10,680 b	9,520 b	11,810 b	9.2	.00	782
				Cadmium				
Balsam fir	1.92 a	0.84 b	1.45 a	0.95 bc	1.41ac	3.6	0.02	0.079
Sugar maple	.88 a	1.32 ab	1.30 ab	1.69 b	1.28ab	2.3	.08	.086
Jack pine	.81	.94	.90	.84	.90	.2	.93	.049
Red pine	—	.59	.76	.84	1.11	.4	.75	.155
Aspen	1.40	1.02	1.34	1.63	1.56	1.0	.40	.106

(Table 6.1 continued on next page)

(Table 6.1 continued)

Forest Type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	MSE[0.5]
				Carbon				
Balsam fir	30	35	31	36	43	1.3	0.30	1.965
Sugar maple	28 ab	21 a	28 ab	35 b	31 b	3.5	.02	1.278
Jack pine	31 a	32 a	37 b	39 b	36 ab	3.1	.03	.658
Red pine	—	24 a	36 b	45 c	27 a	10.5	.00	1.393
Aspen	36 a	29 ab	27 b	37 a	29 ab	2.6	.05	1.244
				Chromium				
Balsam fir	12.9 ab	13.1 a	13.5 a	8.5 ab	6.1 b	2.4	0.09	0.952
Sugar maple	9.7	12.2	13.8	9.6	8.7	1.9	.13	.653
Jack pine	10.1 a	9.9 a	6.5 b	5.3 b	5.3 b	6.3	.00	.425
Red pine	—	9.4 a	8.4 ab	5.8 b	6.5 ab	2.2	.01	.521
Aspen	9.6 ac	13.1 ab	15.5 b	8.4 c	8.9 ac	4.8	.00	.651
				Copper				
Balsam fir	7.1	7.4	10.1	7.8	10.8	1.5	0.24	0.570
Sugar maple	7.2 a	6.1 a	9.4 ab	14.9 b	9.8 ab	2.2	.09	1.040
Jack pine	5.4	5.9	6.3	6.5	6.4	1.0	.44	.220
Red pine	—	5.4	5.5	5.9	5.1	.4	.78	.300
Aspen	10.8	8.9	9.3	8.9	8.4	.7	.58	.430
				Iron				
Balsam fir	6,050 ab	8,920 ab	11,380 a	5,070 b	4,440 b	3.4	0.03	765
Sugar maple	5,570 ab	7,400 ac	9,720 c	4,950 ab	3,790 b	3.5	.02	553
Jack pine	5,370 ab	6,490 a	4,270 bc	3,700 c	3,120 c	5.0	.00	263
Red pine	—	4,790 a	4,010 a	2,780 b	2,670 b	5.6	.01	197
Aspen	5,450 a	8,230 bc	8,740 c	6,320 ab	4,640 a	4.2	.01	377
				Lead				
Balsam fir	53.5 ab	60.9 ab	51.8 a	51.6 a	87.8 b	2.5	0.08	4.730
Sugar maple	17.2 a	37.5 ab	45.8 b	58.4 bc	75.1 c	7.2	.00	3.600
Jack pine	41.4 a	66.7abc	51.6 b	86.4 c	80.6 c	7.1	.00	3.100
Red pine	—	36.5 ab	32.6 a	50.1 bc	59.6 c	5.0	.01	2.840
Aspen	41.0 ab	30.6 a	33.4 a	49.2 ab	57.2 b	2.3	.08	3.160
				Magnesium				
Balsam fir	2,150	1,720	2,210	1,270	2,060	1.2	0.33	177
Sugar maple	2,060 a	1,700 ab	2,120 a	1,250 bc	960 c	6.8	.00	86
Jack pine	1,680 a	1,540 a	1,370 a	820 b	560 b	19.0	.00	50
Red pine	—	1,060 a	1,060 a	950 a	650 b	4.3	.02	46
Aspen	2,660 ab	2,780 ab	3,120 a	1,700 b	1,510 b	2.9	.04	191

(Table 6.1 continued on next page)

(Table 6.1 continued)

Forest type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
				Manganese				
Balsam fir	4,450 a	2,370 b	1,590 bc	1,270 bc	710 c	5.0	0.01	178
Sugar maple	1,130 a	1,800 ab	1,490 a	2,430 b	1,670 ab	2.7	.04	132
Jack pine	1,050 a	1,890 b	1,130 a	1,180 a	420 c	6.0	.00	93
Red pine	—	860	1,020	1,080	1,040	.2	.89	89
Aspen	1,330	1,280	1,200	1,240	910	.5	.75	94
				Nickel				
Balsam fir	13.3 ab	12.9 ab	15.3 b	8.3 a	7.5 a	3.1	0.04	0.911
Sugar maple	12.3	11.7	14.9	9.4	8.9	1.9	.13	.777
Jack pine	10.3 a	11.3 a	7.1 b	5.9 b	5.8 b	7.9	.00	.404
Red pine	—	12.9 a	11.4 a	6.3 b	6.9 b	3.7	.03	.802
Aspen	11.1	14.5	17.5	12.2	7.7	1.8	.14	1.184
				Phosphorus				
Balsam fir	1,073	922	834	862	832	0.3	0.87	48
Sugar maple	862	848	901	955	836	.5	.73	31
Jack pine	750 a	825 a	836 a	738 a	603 b	4.2	.01	20
Red pine	—	569 a	608 a	804 b	507a	10.4	.00	21
Aspen	1,251 a	973 b	894 b	979 b	811 b	3.3	.02	37
				Potassium				
Balsam fir	1,330 ab	1,340 a	1,150 ab	900 b	990ab	1.6	0.22	66
Sugar maple	1,490 a	1,060 b	1,090 b	1,090 b	780 c	7.9	.00	40
Jack pine	1,110 a	1,030 ab	1,000 abc	860 bc	830 c	3.0	.03	30
Red pine	—	780 ab	780 ab	830 a	600 b	2.6	.08	33
Aspen	1,520 a	1,390 a	1,340 a	1,300 ab	810 b	2.0	.12	76
				Sodium				
Balsam fir	90 ab	164 a	131 ab	84 b	70 b	2.5	0.07	11
Sugar maple	105 a	114 a	114 a	92 ab	66 b	3.6	.01	5
Jack pine	98 a	114 a	63 b	65 b	52 b	5.4	.00	78
Red pine	—	83 a	60 ab	52 b	46 b	2.6	.00	5
Aspen	117 ab	150 a	120 a	81 bc	63 c	5.9	.00	6
				Zinc				
Balsam fir	183	158	133	124	161	0.5	0.76	13
Sugar maple	74 a	118 ab	124 b	143 b	110 ab	2.5	.06	7
Jack pine	84 a	120 b	84 a	94 ab	63 a	3.1	.03	5
Red pine	—	64 ab	55 a	87 b	67 ab	3.7	.03	4
Aspen	171	139	137	147	130	.7	.62	8

[1] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[2] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[3] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 7.1.—*Properties of the mineral soil (0 to 25 cm depth) of 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Property[1]	Zone[2]					Anova[3]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
BSAT	93 a[4]	83 a	71 b	52 c	61 c	18.2	0.00	1.622
BD	1.09 ab	1.04 a	1.09 ab	1.17 b	1.19 b	2.6	.04	.016
C	16	19	22	18	18	1.3	.28	.086
CEC	9.1 a	8.0 ab	6.2 bc	5.5 c	5.5 bc	2.7	.03	.396
Ca	7.3 a	5.4 ab	3.5 bc	2.5 c	3.8 bc	5.5	.00	.327
Mg	1.2	1.3	1.0	.7	.8	1.8	.13	.095
K	.28 a	.25 ab	.20 bc	.14 cd	.08 d	10.0	.00	.010
Na	.03	.06	.06	.04	.05	1.4	.25	.004
LOI	32	38	42	34	35	1.3	.28	.155
N	1.0	1.1	1.2	1.0	.9	1.3	.26	.005
pH	5.5 a	4.8 b	4.5 c	4.4 c	4.7 bc	12.7	.00	.048
S	.14	.15	.16	.14	.14	.3	.89	.001
	(23)	(31)	(39)	(42)	(34)			

[1] BSAT = percent base saturation [(Ca + Mg + K + Na) / CEC] * 100; BD = bulk density (Mg m^{-3}); CEC = cation exchange capacity (Ac + Ca + Mg + K + Na) and exchangeable cations - calcium, magnesium, potassium, and sodium (cmol (+) kg^{-1}); LOI = loss on ignition, carbon, nitrogen, and sulfur (g kg^{-1}); pH in 0.01 *M* $CaCl_2$.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 7.2.—*Properties of the mineral soil (0 to 25 cm depth) of 169 plots by forest type across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Property[1]	Forest type[2]					Anova[3]		
	Bf	Sm	Jp	Rp	A	F	P	$MSE^{0.5}$
BSAT	71 a[4]	77 a	59 b	58 b	78 a	6.6	0.00	1.622
BD	.81 a	1.04 b	1.29 c	1.38 c	1.04 b	32.3	.00	.016
C	34 a	21 b	11 c	11 c	21 b	19.8	.00	.086
CEC	10.2 a	7.6 b	3.1 b	2.9 b	9.6 a	14.1	.00	.396
Ca	6.0 a	5.1 a	1.7 b	1.5 b	6.4 a	10.3	.00	.327
Mg	1.9 a	.9 b	.3 c	.2 c	1.6 a	10.6	.00	.095
K	.20 a	.22 a	.11 b	.10 b	.26 a	9.1	.00	.010
Na	.07 a	.04 ab	.03 b	.04 ab	.06 a	2.2	.07	.004
LOI	62 a	41 b	21 c	22 c	41 b	21.0	.00	.155
N	1.6 a	1.3 b	.5 c	.6 c	1.3 b	19.6	.00	.005
pH	4.8 a	4.9 a	4.4 b	4.4 b	5.0 a	6.4	.00	.048
S	.22 a	.17 b	.08 c	.09 c	.17 b	16.7	.00	.001
	(24)	(41)	(39)	(27)	(38)			

[1] BSAT = percent base saturation [(Ca + Mg + K + Na) / CEC] * 100; BD = bulk density (Mg m^{-3}); CEC = cation exchange capacity (Ac + Ca + Mg + K + Na), and exchangeable cations - calcium, magnesium, potassium, and sodium (cmol (+) kg^{-1}); LOI = loss on ignition, and carbon, nitrogen, and sulfur (g kg^{-1}); pH in 0.01 *M* $CaCl_2$.

[2] Forest type: Bf = Balsam fir, Sm = Sugar maple, Jp = Jack pine, Rp = Red pine, A = Aspen.

[3] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 8.1.—*Properties of the mineral soil (0 to 25 cm depth) of 169 plots for five forest types across a Lake States deposition gradient. Number of plots in parentheses.*

Forest type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	MSE[0.5]
				Base Saturation (percent)[3]				
Balsam fir	68 (1)	62 (4)	62 (6)	68 (8)	96 (5)	2.2	0.11	4.329
Sugar maple	99 a[4] (8)	89 ab (8)	77 bc (8)	55 d (9)	67 cd (8)	9.6	.00	2.536
Jack pine	89 a (8)	77 ab (7)	68 b (8)	36 c (8)	27 c (8)	22.3	.00	2.553
Red pine	— —	77 (4)	59 (8)	49 (8)	56 (7)	1.1	.38	4.958
Aspen	95 ab (6)	95 a (8)	83 ab (9)	51 c (9)	73 b (6)	7.6	.00	3.055
				Bulk Density (Mg m^{-3})				
Balsam fir	1.12 a	0.88 a	0.61 b	0.92 a	0.78 ab	3.0	0.05	0.041
Sugar maple	1.07 ab	.88 ac	.87 c	1.11 b	1.25 b	6.2	.00	.029
Jack pine	1.19 ab	1.14 a	1.38 bc	1.40 c	1.33 bc	2.9	.04	.030
Red pine	—	1.35	1.44	1.35	1.38	.3	.81	.040
Aspen	.96	1.06	1.04	1.08	1.05	.3	.90	.035
				Carbon (g kg^{-1})				
Balsam fir	12	26	42	28	48	1.4	0.27	0.437
Sugar maple	22 ab	20 b	30 a	20 b	14 b	2.6	.05	.153
Jack pine	13 a	15 a	9 b	9 b	9 b	3.7	.01	.067
Red pine	—	10	11	14	10	1.6	.21	.072
Aspen	1	25	24	20	22	1.4	.26	.157
				Cation Exchange Capacity (cmol (+) kg^{-1})[3]				
Balsam fir	3.7	10.8	8.9	8.0	15.8	1.2	0.35	1.485
Sugar maple	12.8 a	7.2 b	7.6 b	6.4 b	3.9 b	4.7	.00	.667
Jack pine	4.9 a	4.5 a	2.6 b	2.1 b	1.7 b	12.7	.00	.179
Red pine	—	3.3	2.8	3.4	2.2	1.2	.32	.257
Aspen	10.8	12.7	9.3	7.2	8.1	.6	.64	1.255
				Exchangeable Calcium (cmol (+) kg^{-1})				
Balsam fir	1.9	5.2	4.2	4.5	11.9	1.8	0.17	1.142
Sugar maple	10.5 a	5.3 b	5.0 b	2.7 b	2.6 b	6.8	.00	.560
Jack pine	3.6 a	2.6 b	1.4 c	.5 d	.3 d	22.1	.00	.134
Red pine	—	2.1	1.2	1.8	1.1	.7	.59	.257
Aspen	8.9	9.5	5.7	3.0	6.2	1.4	.25	1.030
				Exchangeable Magnesium (cmol (+) kg^{-1})				
Balsam fir	0.4	2.6	1.1	1.3	3.4	1.0	0.44	0.478
Sugar maple	1.8 a	.9 bc	1.0 b	.6 bc	.3 c	6.1	.00	.097
Jack pine	.7 a	.5 a	.3 b	.1 c	.1 c	26.0	.00	.024
Red pine	—	.3	.2	.2	.2	.6	.63	.035
Aspen	1.3	2.3	2.1	1.1	1.0	1.1	.36	.271

(Table 8.1 continued on next page)

(Table 8.1 continued)

Forest type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
				Exchangeable Potassium (cmol (+) kg^{-1})				
Balsam fir	0.21	0.33	0.22	0.15	0.14	1.8	0.17	0.025
Sugar maple	.45 a	.23 b	.21 b	.16 bc	.07 c	11.3	.00	.019
Jack pine	.16 a	.17 a	.09 b	.07 b	.05 b	15.9	.00	.006
Red pine	—	.15 a	.10 b	.10 ab	.07 b	3.5	.03	.008
Aspen	.23	.35	.35	.21	.11	1.8	.14	.034
				Exchangeable Sodium (cmol (+) kg^{-1})				
Balsam fir	0.01	0.07	0.05	0.05	0.12	1.3	0.32	0.013
Sugar maple	.03	.06	.04	.04	.05	.5	.75	.007
Jack pine	.02	.04	.03	.04	.05	.5	.76	.008
Red pine	—	.07 a	.04 ab	.06 a	.01 b	2.5	.09	.008
Aspen	.06 ab	.08 ab	.11 a	.03 b	.03 b	3.2	.02	.009
				Loss On Ignition (g kg^{-1})				
Balsam fir	23	50	77	50	88	1.5	0.25	0.745
Sugar maple	42 ab	38 b	58 a	39 b	28 b	2.6	.05	.294
Jack pine	26 a	28 a	17 b	18 b	17 b	3.6	.01	.127
Red pine	—	19	21	26	20	1.6	.22	.139
Aspen	28	49	47	38	41	1.4	.26	.301
				Nitrogen (g kg^{-1})				
Balsam fir	0.5	1.3	2.1	1.3	2.2	1.1	0.37	0.022
Sugar maple	1.5	1.2	1.8	1.2	.9	2.1	.11	.010
Jack pine	.6 ab	.7 a	.5 bc	.4 bc	.4 c	3.1	.03	.003
Red pine	—	.6	.5	.7	.5	1.0	.39	.004
Aspen	1.0	1.6	1.4	1.2	1.1	.9	.47	.010
				pH[3]				
Balsam fir	4.4 a	4.2 a	4.4 a	4.7 a	6.1 b	7.2	0.00	0.127
Sugar maple	5.9 a	5.1 b	4.7 bc	4.3 c	4.5 bc	8.9	.00	.094
Jack pine	4.9 a	4.6 ab	4.5 bc	4.2 cd	3.9 d	11.3	.00	.051
Red pine	—	4.6	4.4	4.4	4.4	.3	.81	.077
Aspen	5.9 a	5.2 ab	4.6 bc	4.4 c	5.0 bc	4.7	.00	.118
				Sulfur (g kg^{-1})				
Balsam fir	0.08	0.15	0.25	0.20	0.30	1.3	0.32	0.003
Sugar maple	.20	.16	.21	.16	.13	1.2	.33	.001
Jack pine	.08	.10	.08	.08	.08	1.3	.29	.001
Red pine	—	.09	.08	.10	.08	1.7	.19	.001
Aspen	.14	.19	.17	.17	.19	.4	.79	.002

[1] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[2] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[3] Base Saturation = [(Ca + Mg + K + Na) / CEC] * 100; Cation Exchange Capacity = (Ac + Ca + Mg + K + Na); pH in 0.01 *M* $CaCl_2$.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 9.1.—*Properties of the mineral soil (26 to 50 cm depth) of 169 plots by zone across a Lake States sulfate deposition gradient. Number of plots in parentheses.*

Property[1]	Zone[2]					Anova[3]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
BSAT	92 a[4]	79 b	68 bc	54 d	58 cd	12.9	0.00	1.793
	(23)	(28)	(36)	(42)	(31)			
CEC	6.0	7.7	5.2	4.2	2.8	1.8	.14	.510
Ac	.2 a	.7 b	.9 b	1.4 c	.6 ab	9.3	.00	.064
	(23)	(29)	(36)	(42)	(33)			
Ca	4.3 a	4.6 a	2.6 ab	1.9 b	1.7 b	2.2	.07	.342
	(23)	(28)	(37)	(42)	(32)			
Mg	1.3	2.1	1.4	.8	.4	1.8	.14	.198
	(23)	(28)	(37)	(42)	(31)			
K	.14 a	.13 ab	.10 bc	.08 c	.04 d	8.3	.00	.005
	(23)	(28)	(37)	(42)	(32)			
Na	.05	.08	.05	.05	.04	.8	.56	.006
	(23)	(28)	(37)	(42)	(33)			
pH	5.5 a	5.0 b	4.7 bc	4.6 c	5.0 bc	8.6	.00	.049

[1] BSAT = percent base saturation [(Ca + Mg + K + Na) / CEC] * 100; CEC = cation exchange capacity = (Ac + Ca + Mg + K + Na), Ac = exchangeable acidity, and cations - calcium, magnesium, potassium, and sodium (cmol (+) kg^{-1}); pH in 0.01 *M* $CaCl_2$.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 9.2.—*Properties of the mineral soil (26 to 50 cm depth) of 169 plots by forest type across a Lake States sulfate deposition gradient. Number of plots in parentheses.*

Property[1]	Forest type[2]					Anova[3]		
	Bf	Sm	Jp	Rp	A	F	P	$MSE^{0.5}$
BSAT	72 a[4]	72 a	59 b	57 b	77 a	4.3	0.00	1.793
	(23)	(39)	(38)	(24)	(36)			
CEC	6.2 a	5.2 a	1.7 b	1.9 b	9.7 c	8.3	.00	.510
Ac	1.0 a	1.1 a	.5 b	.7 ab	.9 a	3.0	.02	.064
	(23)	(40)	(38)	(26)	(36)			
Ca	3.2 a	3.0 a	.8 b	.9 ab	5.9 c	7.1	.00	.342
	(23)	(40)	(38)	(25)	(36)			
Mg	1.9 ab	0.9 ac	.2 c	.2 c	2.6 c	5.7	.00	.198
	(23)	(39)	(38)	(25)	(36)			
K	.09 a	.13 a	.06 b	.05 b	.12 a	7.5	.00	.005
	(23)	(40)	(38)	(25)	(36)			
Na	.06 ab	.04 b	.04 b	.04 b	.09 a	3.2	.02	.006
	(23)	(40)	(38)	(26)	(36)			
pH	5.0 ab	4.8 b	4.7 b	4.7 b	5.1 a	3.5	.01	.049
	(23)	(40)	(37)	(27)	(36)			

[1] BSAT = percent base saturation [(Ca + Mg + K + Na) / CEC] * 100; CEC = cation exchange capacity = (Ac + Ca + Mg + K + Na), Ac = exchangeable acidity, and cations - calcium, magnesium, potassium, and sodium (cmol (+) kg^{-1}); pH in 0.01 *M* $CaCl_2$.

[2] Forest type: Bf = Balsam fir, Sm = Sugar maple, Jp = Jack pine, Rp = Red pine, A = Aspen.

[3] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 10.1.—*Properties of the mineral soil (26 to 50 cm depth) of 169 plots by forest type for five zones across a Lake States sulfate deposition gradient. Number of plots in parentheses.*

Forest type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	MSE[0.5]
				Base Saturation (percent)[3]				
Balsam fir	50	59	74	67	96	1.5	0.24	5.131
	(1)	(4)	(6)	(8)	(4)			
Sugar maple	99 a[4]	74 b	73 b	50 c	67 bc	6.6	.00	3.185
	(8)	(7)	(8)	(9)	(7)			
Jack pine	86 a	82 ab	64 b	38 c	30 c	16.5	.00	2.776
	(8)	(6)	(8)	(8)	(8)			
Red pine	—	86	53	52	52	1.6	.23	5.120
	—	(3)	(7)	(8)	(6)			
Aspen	96 a	87 ab	82 abc	59 c	66 bc	3.5	.02	3.618
	(6)	(8)	(7)	(9)	(6)			
				Cation Exchange Capacity (cmol (+) kg^{-1})[3]				
Balsam fir	1.7	11.0	7.1	4.2	5.2	0.6	0.66	1.637
Sugar maple	9.5 a	3.7 b	4.9 b	5.4 b	2.1 b	5.2	.00	.533
Jack pine	2.6 a	2.3 a	1.7 b	1.1 c	.8 c	13.5	.00	.092
Red pine	—	2.2	1.6	2.1	1.7	.3	.79	.229
Aspen	6.7	15.7	11.4	7.7	5.7	.9	.47	1.929
				Exchangeable Acidity (cmol (+) kg^{-1})				
Balsam fir	0.9	1.6	0.9	1.2	0.1	1.6	0.22	0.195
	(1)	(4)	(6)	(8)	(4)			
Sugar maple	.1 a	.9 ab	1.3 bc	2.0 c	.8 ab	6.3	.00	.131
	(8)	(7)	(8)	(9)	(8)			
Jack pine	.2 a	.4 ab	.6 b	.7 b	.6 b	2.4	.07	.051
	(8)	(6)	(8)	(8)	(8)			
Red pine	—	.2	.8	.9	.6	1.3	.31	.122
	—	(4)	(7)	(8)	(7)			
Aspen	.1 a	.6 a	.9 ab	1.9 b	.7 a	3.0	.03	.177
	(6)	(8)	(7)	(9)	(6)			
				Exchangeable Calcium (cmol (+) kg^{-1})				
Balsam fir	0.5	4.6	3.7	2.1	3.7	0.5	0.77	0.797
	(1)	(4)	(6)	(8)	(4)			
Sugar maple	7.0 a	2.0 b	2.7 b	2.4 b	1.1 b	7.9	.00	.363
	(8)	(7)	(8)	(9)	(8)			
Jack pine	1.8 a	1.5 a	.8 b	.3 bc	.1 c	15.1	.00	.084
	(8)	(6)	(8)	(8)	(8)			
Red pine	—	1.6	.6	1.0	.8	1.0	.43	.171
	—	(3)	(8)	(8)	(6)			
Aspen	4.9	10.4	6.2	3.7	4.0	.8	.51	1.388
	(6)	(8)	(7)	(9)	(6)			

(Table 10.1 continued on next page)

(Table 10.1 continued)

Forest type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
				Exchangeable Magnesium (cmol(+) kg^{-1})				
Balsam fir	0.3	4.4	2.4	0.8	1.4	0.6	0.67	0.857
	(1)	(4)	(6)	(8)	(4)			
Sugar maple	2.2 a	.6 b	.8 b	.8 b	.2 b	5.6	.00	.144
	(8)	(7)	(8)	(9)	(8)			
Jack pine	.4 a	.3 ab	.2 b	.1 c	.1 c	15.3	.00	.020
	(8)	(6)	(8)	(8)	(8)			
Red pine	—	.2	.2	.1	.2	.5	.69	.027
	—	(3)	(8)	(8)	(6)			
Aspen	1.5	4.4	4.1	1.9	.8	1.1	.40	.693
	(6)	(8)	(7)	(9)	(6)			
				Exchangeable Potassium (cmol (+) kg^{-1})				
Balsam fir	0.09 ab	0.19 b	0.09 ab	0.08 a	0.03 a	4.047	0.016	0.013
	(1)	(4)	(6)	(8)	(4)			
Sugar maple	.22 a	.13 b	.14 b	.11 bc	.04 c	5.620	.001	.012
	(8)	(7)	(8)	(9)	(8)			
Jack pine	.09 a	.08 ab	.06 bc	.04 cd	.02 d	15.246	.000	.003
	(8)	(6)	(8)	(8)	(8)			
Red pine	—	.08	.05	.05	.04	1.828	.173	.005
	—	(3)	(8)	(8)	(6)			
Aspen	.09	.16	.16	.12	.07	1.063	.391	.017
	(6)	(8)	(7)	(9)	(6)			
				Exchangeable Sodium (cmol (+) kg^{-1})				
Balsam fir	0.01	0.12	0.09	0.01	0.06	1.3	0.31	0.020
	(1)	(4)	(6)	(8)	(4)			
Sugar maple	.02	.05	.06	.05	.03	.7	.60	.007
	(8)	(7)	(8)	(9)	(8)			
Jack pine	.04	.04	.03	.03	.06	.5	.75	.008
	(8)	(6)	(8)	(8)	(8)			
Red pine	—	.08 a	.03 ab	.07 a	.01 b	3.4	.04	.009
	—	(3)	(8)	(8)	(7)			
Aspen	.10	.10	.09	.08	.08	.1	.98	.017
	(6)	(8)	(7)	(9)	(6)			
				pH[3]				
Balsam fir	4.4 a	4.6 a	4.9 a	4.8 a	6.1 b	3.2	0.04	0.143
Sugar maple	5.7 a	4.7 b	4.7 b	4.4 b	4.5 b	17.0	.00	.057
Jack pine	5.0 a	4.9 ab	4.6 bc	4.5 c	4.4 c	6.9	.00	.047
Red pine	—	4.9	4.5	4.6	4.8	1.2	.34	.071
Aspen	5.9	5.5	4.7	4.7	4.9	2.1	.11	.160

[1] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[2] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[3] Base Saturation = [(Ca + Mg + K + Na) / CEC] * 100; Cation Exchange Capacity = (Ac + Ca + Mg + K + Na); pH in 0.01 *M* $CaCl_2$.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 11.1.—*Properties of the mineral soil (51 to 75 cm depth) of 169 plots by zone across a Lake States sulfate deposition gradient. Number of plots in parentheses.*

Property[1]	Zone[2]					Anova[3]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
BSAT	94 a[4]	85 a	71 b	59 c	64 bc	12.5	0.00	1.789
	(23)	(25)	(34)	(40)	(31)			
CEC	10.1 a	7.9 ab	6.6 abc	5.1 bc	3.1 c	2.7	.03	.631
Ac	.2 a	.5 abc	.7 bc	.8 c	.4 ab	4.0	.00	.056
	(23)	(25)	(35)	(40)	(33)			
Ca	7.6 a	5.8 ab	4.1 bc	3.1 bc	2.0 c	2.8	.03	.500
	(23)	(26)	(34)	(40)	(32)			
Mg	2.1 ab	2.7 a	1.6 abc	1.0 bc	.6 c	3.0	.02	.206
K	.12 a	.10 ab	.10 a	.06 bc	.03 c	6.6	.00	.006
Na	.10	.11	.08	.06	.05	1.5	.20	.008
	(23)	(26)	(34)	(40)	(33)			
pH	5.7 a	5.2 b	5.0 b	5.0 b	5.2 b	3.5	.01	.070
	(23)	(25)	(35)	(39)	(33)			

[1] BSAT = percent base saturation [(Ca + Mg + K + Na) / CEC] * 100; CEC = cation exchange capacity = (Ac + Ca + Mg + K + Na), Ac = exchangeable acidity, and cations - calcium, magnesium, potassium, and sodium (cmol (+) kg^{-1}); pH in 0.01 *M* $CaCl_2$.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 11.2.—*Properties of the mineral soil (51 to 75 cm depth) of 169 plots by forest type across a Lake States sulfate deposition gradient. Number of plots in parentheses.*

Property[1]	Forest type[2]					Anova[3]		
	Bf	Sm	Jp	Rp	A	F	P	$MSE^{0.5}$
BSAT	84 a[4]	76 a	64 b	59 b	82 a	7.0	0.00	1.789
	(17)	(39)	(37)	(26)	(34)			
CEC	6.6 a	7.7 a	1.6 b	1.7 b	12.9 c	11.4	.00	.631
Ac	.5	.7	.3	.7	.6	1.8	.12	.056
	(17)	(40)	(38)	(27)	(34)			
Ca	5.3 ab	5.1 a	.9 c	.8 c	8.9 b	9.1	.00	.500
	(18)	(39)	(38)	(26)	(34)			
Mg	.3 ab	.2 b	2.4 c	1.7 c	3.2 a	7.8	.00	.206
K	.11 a	.12 a	.04 b	.04 b	.09 a	7.2	.00	.006
	(18)	(39)	(37)	(27)	(34)			
Na	.11 ab	.07 bc	.04 c	.04 c	.14 a	5.8	.00	.008
	(18)	(39)	(38)	(27)	(34)			
pH	5.7 a	5.0 b	4.9 b	4.8 b	5.6 a	6.8	.00	.070
	(18)	(40)	(36)	(27)	(34)			

[1] BSAT = percent base saturation [(Ca + Mg + K + Na) / CEC] * 100; CEC = cation exchange capacity = (Ac + Ca + Mg + K + Na), Ac = exchangeable acidity, and cations - calcium, magnesium, potassium, and sodium (cmol (+) kg^{-1}); pH in 0.01 *M* $CaCl_2$.

[2] Forest type: Bf = Balsam fir, Sm = Sugar maple, Jp = Jack pine, Rp = Red pine, A = Aspen.

[3] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 12.1.—*Properties of the mineral soil (51 to 75 cm depth) of 169 plots by forest type for five zones across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Forest type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
				Base Saturation (percent)[3]				
Balsam fir	73	59	81	81	100	0.8	0.56	5.977
	(1)	(1)	(5)	(6)	(4)			
Sugar maple	99 a[4]	83 ab	79 ab	60 b	63 b	3.5	.02	3.868
	(8)	(7)	(7)	(9)	(8)			
Jack pine	89 a	89 a	62 b	39 c	43 c	18.1	.00	2.528
	(8)	(6)	(8)	(8)	(7)			
Red pine	—	81	56	50	62	1.4	.27	4.863
	—	(4)	(8)	(8)	(6)			
Aspen	99 a	91 ab	87 abc	71 bc	68 c	2.9	.04	3.517
	(6)	(7)	(6)	(9)	(6)			
				Cation Exchange Capacity (cmol (+) kg^{-1})[3]				
Balsam fir	1.9	1.6	10.0	5.6	6.2	0.7	0.60	1.500
Sugar maple	17.2 a	8.5 b	6.3 bc	5.2 bc	1.4 c	7.5	.00	.972
Jack pine	3.6 a	2.1 ab	1.4 b	.6 b	.5 b	3.7	.01	.304
Red pine	—	2.5	1.6	1.7	1.3	.7	.58	.271
Aspen	10.8	16.3	17.6	11.7	8.1	.5	.75	2.444
				Exchangeable Acidity (cmol (+) kg^{-1})				
Balsam fir	0.5	0.7	0.6	0.6	0.0	0.7	0.63	0.165
	(1)	(1)	(5)	(6)	(4)			
Sugar maple	.2 a	.7 ab	1.0 b	1.1 b	.5 ab	2.6	.06	.102
	(8)	(7)	(8)	(9)	(8)			
Jack pine	.2 a	.2 a	.5 b	.4 ab	.3 ab	2.7	.05	.320
	(8)	(6)	(8)	(8)	(8)			
Red pine	—	.5	.8	.8	.4	.6	.70	.160
	—	(4)	(8)	(8)	(7)			
Aspen	.1	.6	.5	1.2	.6	1.0	0.42	.179
	(6)	(7)	(6)	(9)	(6)			
				Exchangeable Calcium (cmo l(+) kg^{-1})				
Balsam fir	0.8	9.8	7.8	3.4	4.0	0.9	0.52	1.419
	(1)	(2)	(5)	(6)	(4)			
Sugar maple	13.0 a	5.7 b	3.4 b	3.0 b	.7 b	7.8	.00	.765
	(8)	(7)	(7)	(9)	(6)			
Jack pine	2.5 a	1.4 ab	.6 b	.1 b	.1 b	4.6	.01	.215
	(8)	(6)	(8)	(8)	(8)			
Red pine	—	1.6 a	.6 b	.6 b	.6 b	3.3	.04	.111
	—	(4)	(8)	(8)	(6)			
Aspen	8.2	11.0	11.0	8.0	6.2	.2	.93	1.964
	(6)	(7)	(6)	(9)	(6)			

(Table 12.1 continued on next page)

(Table 12.1 continued)

Forest type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
				Exchangeable Magnesium (cmol (+) kg^{-1})				
Balsam fir	0.4	10.2	1.1	1.5	2.2	2.0	0.15	0.976
Sugar maple	3.6 a	2.1 ab	1.6 bc	1.0 bc	.2 c	5.5	.00	.253
Jack pine	.8 a	.4 ab	.2 b	.1 b	.1 b	2.9	.04	.082
Red pine	—	.3	.2	.2	.2	.3	.80	.034
Aspen	2.3	4.5	5.7	2.3	1.1	1.5	.22	.661
				Exchangeable Potassium (cmol (+) kg^{-1})				
Balsam fir	0.07	0.17	0.19	0.07	0.03	0.8	0.53	0.035
Sugar maple	.22 a	.13 b	.12 b	.09 bc	.03 c	6.4	.00	.013
Jack pine	.07 a	.07 a	.05 b	.03 b	.02 c	8.6	.00	.004
Red pine	—	.06 a	.05 a	.03 b	.03 b	2.9	.05	.004
Aspen	.08	.10	.12	.09	.07	.6	.70	.012
				Exchangeable Sodium (cmol (+) kg^{-1})				
Balsam fir	0.13	0.30	0.15	0.04	0.07	1.2	0.35	0.037
	(1)	(2)	(5)	(6)	(4)			
Sugar maple	.11	.09	.06	.04	.04	1.2	.35	.068
	(8)	(7)	(7)	(9)	(8)			
Jack pine	.05	.04	.03	.04	.05	.3	.91	.008
	(8)	(6)	(8)	(8)	(8)			
Red pine	—	.08	.03	.05	.03	1.7	.19	.008
	—	(4)	(8)	(8)	(7)			
Aspen	.15	.14	.20	.12	.09	.4	.83	.027
	(6)	(7)	(6)	(9)	(6)			
				pH[3]				
Balsam fir	**4.6**	**5.0**	**5.4**	**5.5**	**6.9**	**2.0**	**0.16**	**0.243**
	(1)	(2)	(5)	(6)	(4)			
Sugar maple	**5.8 a**	**4.7 b**	**4.8 b**	**4.8 b**	**4.9 b**	**2.9**	**.04**	**.122**
	(8)	(7)	(8)	(9)	(8)			
Jack pine	**5.4 a**	**5.1 ab**	**4.7 b**	**4.6 b**	**4.6 b**	**5.5**	**.00**	**.071**
	(8)	(5)	(8)	(7)	(8)			
Red pine	—	4.9 ab	4.6 a	4.7 a	5.1 b	2.6	.08	.071
	—	(4)	(8)	(8)	(7)			
Aspen	6.1	5.9	5.9	5.4	5.2	.5	.72	.233
	(6)	(7)	(6)	(9)	(6)			

[1] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[2] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[3] Base Saturation = [(Ca + Mg + K + Na) / CEC] * 100; CEC = cation exchange capacity = (Ac + Ca + Mg + K + Na); pH in 0.01 *M* $CaCl_2$.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 13.1.—*Properties of the mineral soil (76 to 100 cm depth) of 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Property[1]	Zone[2]					Anova[3]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
BSAT	96 a[4]	89 a	76 b	67 b	66 b	9.2	0.00	1.901
	(22)	(26)	(27)	(35)	(30)			
CEC	11.1 a	11.0 a	7.0 ab	6.1 b	2.3 b	3.4	.01	.780
Ac	.1 a	.4 b	.4 ab	.6 b	.1 a	2.9	.02	.088
	(22)	(26)	(27)	(36)	(31)			
Ca	8.3 a	7.5 ab	4.6 abc	4.0 bc	1.8 c	2.7	.03	.611
	(22)	(26)	(29)	(37)	(30)			
Mg	2.4 a	2.8 a	1.7 ab	1.2 bc	.5 c	4.2	.00	.188
	(22)	(26)	(29)	(36)	(31)			
K	.10 a	.10 a	.07 b	.06 b	.02 c	10.9	.00	.004
	(22)	(26)	(29)	(37)	(31)			
Na	.14 a	.13 a	.10 ab	.07 b	.05 b	3.0	.02	.010
pH	6.2 a	5.4 b	5.1 b	5.2 b	5.3 b	6.2	.00	.076
	(22)	(25)	(29)	(36)	(31)			

[1] BSAT = percent base saturation [(Ca + Mg + K + Na) / CEC] * 100; CEC = cation exchange capacity = (Ac + Ca + Mg + K + Na), Ac = exchangeable acidity, and exchangeable cations - calcium, magnesium, potassium, and sodium (cmol(+) kg^{-1}); pH in 0.01 *M* $CaCl_2$.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 13.2.—*Properties of the mineral soil (76 to 100 cm depth) of 169 plots by forest type across a Lake States sulfate deposition gradient. Number of plots in parentheses.*

Property[1]	Forest Type[2]					Anova[3]		
	Bf	Sm	Jp	Rp	A	F	P	$MSE^{0.5}$
BSAT	91 a[4]	81 a	66 b	65 b	91 a	7.8	0.00	1.901
	(13)	(34)	(37)	(25)	(31)			
CEC	9.1 a	9.9 a	1.3 b	1.5 b	14.9 a	11.4	.00	.780
Ac	.2	.6	.2	.1	.3	1.0	.38	.088
	(13)	(35)	(37)	(26)	(31)			
Ca	5.5 ab	6.7 b	.8 c	1.0 ac	10.8 d	9.8	.00	.611
	(13)	(36)	(37)	(26)	(32)			
Mg	3.2 a	2.2 a	.2 b	.3 b	3.1 a	10.8	.00	.188
	(13)	(35)	(37)	(27)	(32)			
K	.08 ab	.11 a	.04 c	.04 c	.08 b	10.0	.00	.004
	(13)	(36)	(37)	(27)	(32)			
Na	.13 ab	.11 a	.04 c	.04 c	.16 b	6.6	.00	.010
pH	6.0 a	5.4 b	5.0 b	5.0 b	6.0 a	8.3	.00	.076
	(13)	(36)	(36)	(26)	(32)			

[1] BSAT = percent base saturation [(Ca + Mg + K + Na) / CEC] * 100; CEC = cation exchange capacity = (Ac + Ca + Mg + K + Na), Ac = exchangeable acidity, and exchangeable cations - calcium, magnesium, potassium, and sodium (cmol(+) kg^{-1}); pH in 0.01 *M* $CaCl_2$.

[2] Forest type: Bf = Balsam fir, Sm = Sugar maple, Jp = Jack pine, Rp = Red pine, A = Aspen.

[3] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 14.1.—*Properties of the mineral soil (76 to 100 cm depth) of 169 plots by forest type for five zones across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Forest type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
				Base Saturation (percent)[3]				
Balsam fir	86	85	98	85	100	0.3	0.85	6.017
	(1)	(2)	(2)	(5)	(3)			
Sugar maple	100 a[4]	87 a	81 ab	81 a	57 b	4.1	.01	3.699
	(8)	(7)	(4)	(7)	(8)			
Jack pine	92 a	88 ab	69 bc	32 d	50 cd	12.7	.00	3.174
	(8)	(6)	(8)	(7)	(8)			
Red pine	—	87	64	55	66	1.3	.30	5.201
	—	(4)	(7)	(8)	(6)			
Aspen	99	94	90	87	83	.5	.73	3.651
	(5)	(7)	(6)	(8)	(5)			
				Cation Exchange Capacity (cmol (+) kg^{-1})[3]				
Balsam fir	1.3	20.4	18.0	5.6	3.8	1.4	0.32	2.946
Sugar maple	17.9 a	12.0 a	7.6 ab	8.9 ab	1.9 b	3.0	.03	1.624
Jack pine	3.0 a	1.9 ab	.8 bc	.5 c	.5 c	7.6	.00	.184
Red pine	—	2.1	1.2	2.2	.6	.3	.82	1.541
Aspen	15.1	20.1	18.1	12.9	6.9	.6	.64	2.763
				Exchangeable Acidity (cmol (+) kg^{-1})				
Balsam fir	0.2	0.3	0.2	0.4	0.0	0.3	0.85	0.138
	(1)	(2)	(2)	(5)	(3)			
Sugar maple	.1 a	.7 ab	.9 b	1.0 b	.4 ab	2.8	.04	.102
	(8)	(7)	(4)	(8)	(8)			
Jack pine	.1	.2	.2	.3	.2	1.0	.42	.029
	(8)	(6)	(8)	(7)	(8)			
Red pine	—	.3	.5	.0	.0	1.5	.24	.441
	—	(4)	(7)	(8)	(7)			
Aspen	.1	.5	.3	.3	.1	1.3	.29	.079
	(5)	(7)	(6)	(8)	(5)			
				Exchangeable Calcium (cmol (+) kg^{-1})				
Balsam fir	0.8	10.2	13.2	3.3	2.3	1.6	0.26	1.680
	(1)	(2)	(2)	(5)	(3)			
Sugar maple	13.4 a	8.4 ab	4.2 b	5.6 ab	1.1 b	2.9	.04	1.284
	(8)	(7)	(5)	(8)	(8)			
Jack pine	2.1 a	1.2 b	.4 c	.1 c	.1 c	10.0	.00	.126
	(8)	(6)	(8)	(7)	(8)			
Red pine	—	1.5	.5	.8	1.5	1.2	.33	.211
	—	(4)	(8)	(8)	(6)			
Aspen	11.6	14.5	13.1	8.8	5.9	.4	.78	2.264
	(5)	(7)	(6)	(9)	(5)			

(Table 14.1 continued on next page)

(Table 14.1 continued)

Forest type	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	$MSE^{0.5}$
				Exchangeable Magnesium (cmol (+) kg^{-1})				
Balsam fir	0.2	9.5	4.2	1.8	1.4	1.2	0.40	1.340
	(1)	(2)	(2)	(5)	(3)			
Sugar maple	4.1 a	2.6 ab	2.5 abc	1.7 bc	.3 c	3.8	.01	.333
	(8)	(7)	(5)	(7)	(8)			
Jack pine	.7 a	.3 ab	.1 b	.1 b	.1 b	4.0	.01	.061
	(8)	(6)	(8)	(7)	(8)			
Red pine	—	.2	.2	.3	.6	.7	.58	.117
	—	(4)	(8)	(8)	(7)			
Aspen	3.1	4.8	4.4	2.2	.9	1.9	.14	.511
	(5)	(7)	(6)	(9)	(5)			
				Exchangeable Potassium (cmol (+) kg^{-1})				
Balsam fir	0.05	0.18	0.10	0.07	0.02	2.0	0.18	0.018
	(1)	(2)	(2)	(5)	(3)			
Sugar maple	.18 a	.14 ab	.12 ab	.08 bc	.03 c	5.8	.00	.012
	(8)	(7)	(5)	(8)	(8)			
Jack pine	.06 a	.07 a	.03 b	.02 bc	.01 c	12.0	.00	.003
	(8)	(6)	(8)	(7)	(8)			
Red pine	—	.06	.05	.04	.03	1.5	.24	.005
	—	(4)	(8)	(8)	(7)			
Aspen	.07	.09	.11	.07	.04	1.3	.30	.010
	(5)	(7)	(6)	(9)	(5)			
				Exchangeable Sodium (cmol (+) kg^{-1})				
Balsam fir	0.01	0.26	0.37	0.03	0.10	1.9	0.21	0.047
	(1)	(2)	(2)	(5)	(3)			
Sugar maple	.17	.17	.09	.07	.03	1.5	.21	.023
	(8)	(7)	(5)	(8)	(8)			
Jack pine	.05	.03	.03	.03	.05	.3	.88	.009
	(8)	(6)	(8)	(7)	(8)			
Red pine	—	.07	.02	.05	.02	2.0	.14	.007
	—	(4)	(8)	(8)	(7)			
Aspen	.27	.17	.22	.12	.07	1.5	.22	.027
	(5)	(7)	(6)	(9)	(5)			
				pH[3]				
Balsam fir	5.2	5.5	6.6	5.6	6.8	1.006	0.458	0.300
	(1)	(2)	(2)	(5)	(3)			
Sugar maple	6.6 a	5.1 b	4.8 b	5.1 b	5.0 b	4.446	.006	.154
	(8)	(7)	(5)	(8)	(8)			
Jack pine	5.4 a	5.1 ab	4.8 b	4.7 b	4.8 b	4.237	.008	.070
	(8)	(5)	(8)	(7)	(8)			
Red pine	—	4.9 ab	4.8 a	4.7 a	5.5 b	3.022	.051	.108
	—	(4)	(8)	(8)	(7)			
Aspen	7.1	6.0	5.8	5.7	5.5	1.102	.376	.239
	(5)	(7)	(6)	(9)	(5)			

[1] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[2] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[3] Base Saturation = [(Ca + Mg + K + Na) / CEC] * 100; CEC = cation exchange capacity = (Ac + Ca + Mg + K + Na); pH in 0.01 *M* $CaCl_2$.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 15.1.—*Mean growth (mm), ash content (g kg^{-1}), and elemental concentration (mg kg^{-1}) in the 1976-1985 increment of woody tissue of five tree species on 169 plots by zone across a Lake States deposition gradient. Number of observations in parentheses.*

Element	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	MSE$^{0.5}$
Growth	15.2	15.8	17.0	17.3	15.3	0.7	0.57	0.421
	(23)	(31)	(39)	(42)	(34)			
Ash	13	13	13	13	13	.1	.98	.24
	(16)	(26)	(32)	(30)	(24)			
Aluminum	7.0 a[3]	8.8 bc	9.8 c	9.1 c	7.3 ab	3.6	.01	.239
	(16)	(26)	(33)	(31)	(25)			
Boron	3.4 ab	3.5 ab	6.9 b	2.4 a	2.3 a	3.0	.02	.541
Cadmium	.28	.20	.33	.25	.21	.5	.76	.259
	(16)	(26)	(33)	(31)	(24)			
Calcium	742	813	712	718	785	1.4	.24	16
	(16)	(26)	(33)	(31)	(25)			
Chromium	.31 a	.47 ab	.36 a	.64 b	.49 ab	2.2	.08	.036
Copper	1.1	1.3	1.3	1.2	1.2	1.3	.26	.031
Iron	100 ab	95 ab	59 b	101 a	67 ab	3.1	.02	6
Lead	.33	.64	.50	.52	.45	1.9	.11	.031
Magnesium	127	134	135	138	150	1.1	.38	3
Manganese	16.6 a	30.1 ab	37.4 c	52.2 c	75.6 d	7.1	.00	3
Nickel	.50 ab	.57 b	.41 ab	.52 ab	.31 a	2.2	.08	.038
	(16)	(25)	(33)	(31)	(25)			
Nitrogen	710 a	654 ab	688 a	624 b	619 b	3.0	.02	10
	(22)	(31)	(39)	(38)	(34)			
Phosphorus	108 a	100 ab	95 ab	90 b	91 b	2.8	.03	2
	(16)	(26)	(33)	(31)	(25)			
Potassium	616	629	556	594	679	1.1	.38	23
Sodium	5.6 a	7.8 ab	11.5 bc	13.0 c	6.3 a	3.1	.02	.759
	(16)	(26)	(33)	(30)	(25)			
Sulfur	86	81	83	78	82	1.7	.14	1
	(23)	(31)	(39)	(42)	(34)			
Zinc	10.5 a	12.5 ab	14.6 bc	17.0 c	11.2 a	5.485	.000	.528

[1] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[2] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[3] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 15.2.—*Mean growth (mm), ash content (g kg^{-1}), and elemental concentration (mg kg^{-1}) in the 1976-1985 increment of woody tissue of five tree species on 169 plots by forest type across a Lake States deposition gradient. Number of observations in parentheses.*

Element	Forest type[1]					Anova[2]		
	Bf	Sm	Jp	Rp	A	F	P	MSE$^{0.5}$
Growth	12.1 a[3] (24)	12.5 a (41)	13.3 a (39)	25.5 b (27)	19.5 c (38)	33.3	0.00	0.421
Ash	17 a (9)	12 b (28)	12 b (29)	14 c (27)	13 bc (35)	6.1	.00	.24
Aluminum	10.6 a (10)	4.0 b (30)	12.1 a (29)	13.7 c (27)	5.2 b (35)	70.8	.00	.239
Boron	6.3 ab	3.7 abc	1.8 c	6.6 b	2.8 ac	2.9	.02	.541
Cadmium	.17 (10)	.18 (30)	.29 (28)	.44 (27)	.19 (35)	1.8	.13	.259
Calcium	792 a (10)	604 a (30)	546 b (29)	631 b (27)	957 c (35)	23.3	.00	16
Chromium	.63 ab	.41 a	.38 a	.72 b	.34 a	3.8	.01	.036
Copper	1.4 ab	1.3 a	.9 c	1.1 b	1.4 a	11.6	.00	.031
Iron	177 a	77 b	71 b	82 b	70 b	5.9	.00	6
Lead	.74 a	.48 bc	.53 abc	.58 ab	.37 c	2.5	.04	.031
Magnesium	152 a	118 b	125 b	144 a	154 a	5.5	.00	3
Manganese	54.3 a	55.7 a	39.0 a	82.5 b	6.3 c	18.4	.00	3
Nickel	.55 b (10)	.55 b (30)	.32 a (29)	.64 b (27)	.32 a (34)	3.9	.01	.038
Nitrogen	711 ab (21)	774 a (39)	662 bc (39)	626 c (27)	517 d (38)	21.0	.00	10
Phosphorus	81 a (10)	118 b (30)	76 a (29)	86 a (27)	104 c (35)	17.0	.00	2
Potassium	1,200 a	731 b	455 c	413 c	617 b	20.5	.00	23
Sodium	8.4 ab (10)	8.2 a (30)	9.9 ab (29)	14.0 b (27)	6.8 a (34)	2.4	.05	.759
Sulfur	81 a (24)	102 b (41)	75 c (39)	78 ac (27)	70 d (38)	48.7	.00	1
Zinc	14.0 a	5.6 b	15.2 a	13.6 a	19.0 c	21.3	.00	.528

[1] Forest type: Bf = Balsam fir, Sm = Sugar maple, Jp = Jack pine, Rp = Red pine, A = Aspen.

[2] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[3] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 16.1.—*Mean growth (mm), ash content (g kg^{-1}), and elemental concentration (mg kg^{-1}) in the 1966-1975 increment of woody tissue of five tree species on 169 plots by zone across a Lake States deposition gradient. Number of observations in parentheses.*

Element	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	MSE$^{0.5}$
Growth	18.4	22.1	22.2	21.4	20.2	0.6	0.66	0.566
	(23)	(31)	(39)	(42)	(34)			
Ash	13	13	15	14	13	1.6	.18	.20
	(20)	(28)	(34)	(33)	(27)			
Aluminum	5.5 a[3]	6.7 b	7.1 b	6.5 b	5.6 a	3.0	.02	.143
	(20)	(29)	(36)	(35)	(28)			
Boron	4.5 ab	3.3 a	6.6 b	2.3 a	2.2 a	3.6	.01	.518
Cadmium	.20	.38	.31	.31	.27	.5	.75	.039
Calcium	905	967	904	892	955	2.0	.09	16
Chromium	.27 a	.26 a	.25 a	.42 b	.35 ab	2.8	.03	.019
Copper	.84 ab	.87 ab	.88 b	.76 a	.78 ab	2.5	.05	.021
Iron	58 ab	46 ac	36 c	68 b	38 ac	4.8	.00	3
Lead	.38	.55	.65	.43	.40	1.8	.13	.037
Magnesium	128	165	174	171	194	1.2	.32	4
Manganese	20.3 a	45.7 b	51.1 b	59.0 b	90.0 c	5.3	.00	3
Nickel	.38	.50	.41	.38	.23	1.9	.11	.037
Nitrogen	529 a	480 b	480 b	451 bc	434 c	4.4	.00	6
	(23)	(31)	(39)	(42)	(34)			
Phosphorus	57	47	49	47	49	1.9	.12	1
	(20)	(29)	(36)	(35)	(28)			
Potassium	449	611	539	609	531	1.0	.39	17
Sodium	4.2 ab	6.1 b	6.1 b	5.1 ab	3.5 a	2.2	.08	.346
	(20)	(29)	(36)	(35)	(28)			
Sulfur	75 a	71 abc	73 ab	67 c	69 bc	3.0	.02	1
	(23)	(31)	(39)	(42)	(34)			
Zinc	9.0 a	11.0 ab	12.7 b	15.1 c	12.2 b	11.8	.00	.307

[1] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[2] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[3] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 16.2.—*Mean growth (mm), ash content (g kg^{-1}), and elemental concentration (mg kg^{-1}) in the 1966-1975 increment of woody tissue of five tree species on 169 plots by forest type across a Lake States deposition gradient. Number of observations in parentheses.*

Element	Forest type[1]					Anova[2]		
	Bf	Sm	Jp	Rp	A	F	P	MSE$^{0.5}$
Growth	18.3 a[3] (24)	15.6 a (41)	16.6 a (39)	34.9 b (27)	23.5 c (38)	34.3	0.00	0.566
Ash	18 a (16)	11 b (33)	13 c (31)	15 d (26)	14 d (36)	23.1	.00	.20
Aluminum	8.3 ab (18)	3.6 c (36)	7.4 a (31)	9.2 b (27)	5.1 d (36)	51.9	.00	.143
Boron	4.2 ab	4.1 ab	1.6 a	7.1 b	2.7 a	4.0	.00	.518
Cadmium	.19	.20	.30	.44	.35	1.3	.28	.039
Calcium	1,220 a	866 b	683 c	906 b	1,050 d	29.9	.00	16
Chromium	.51 a	.24 b	.25 b	.52 a	.19 b	11.4	.00	.019
Copper	.81 a	.81 a	.57 b	.75 a	1.1 c	21.2	.00	.021
Iron	87 a	38 bc	51 bc	55 b	35 c	7.2	.00	3
Lead	.42 ab	.33 a	.51 ab	.68 b	.56 b	2.5	.04	.037
Magnesium	253 a	121 b	139 c	226 a	156 c	30.0	.00	4
Manganese	67.5 a	50.5 a	50.6 a	122.6 b	6.8 c	29.1	.00	3
Nickel	.48 ab	.33 b	.27 b	.63 a	.29 b	4.0	.00	.037
Nitrogen	418 a (24)	614 c (41)	428 ab (39)	468 b (27)	393 a (38)	41.3	.00	6
Phosphorus	12 a (18)	69 b (36)	40 c (31)	54 d (27)	52 d (36)	108.1	.00	1
Potassium	1,640 a	580 b	287 c	298 c	416 d	151.3	.00	17
Sodium	6.0 (18)	5.3 (36)	5.2 (31)	5.6 (27)	4.1 (36)	.8	.54	.346
Sulfur	66 ad (24)	92 b (41)	57 c (39)	72 d (27)	64 a (38)	69.5	.00	1
Zinc	11.6 a	5.6 b	15.1 cd	13.9 c	15.9 d	44.8	.00	.307

[1] Forest type: Bf = Balsam fir, Sm = Sugar maple, Jp = Jack pine, Rp = Red pine, A= Aspen.

[2] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[3] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 17.1.—*Mean growth (mm), ash content (g kg^{-1}), and elemental concentration (mg kg^{-1}) in the 1956-1965 increment of woody tissue of five tree species on 169 plots by zone across a Lake States deposition gradient. Number of observations in parentheses.*

Element	Zone[1]					Anova[2]		
	1	2	3	4	5	F	P	MSE$^{0.5}$
Growth	21.3	21.9	23.2	21.8	19.2	1.8	0.12	0.519
	(23)	(29)	(33)	(39)	(31)			
Ash	14	14	14	14	14	.9	.45	.20
	(19)	(29)	(32)	(39)	(28)			
Aluminum	6.1 ab[3]	6.7 bc	6.8 bc	7.6 c	5.5 a	2.5	.04	.188
	(18)	(30)	(32)	(40)	(29)			
Boron	4.8 a	3.4 ab	4.7 a	2.4 ab	2.2 b	3.2	.02	.361
	(19)	(30)	(32)	(40)	(29)			
Cadmium	.26	.30	.30	.34	.32	.1	.97	.031
Calcium	1,220 a	1,160 ab	1,060 bc	1,040 bc	1,010 c	4.5	.00	22
	(18)	(30)	(32)	(40)	(29)			
Chromium	.23 a	.24 a	.24 a	.39 b	.30 ab	2.8	.03	.015
Copper	.9 a	.8 ab	.9 a	.7 bc	.6 c	3.6	.01	.029
	(19)	(30)	(32)	(40)	(29)			
Iron	53 ab	43 bc	33 c	58 a	36 bc	3.6	.01	3
Lead	.33	.39	.46	.43	.46	1.2	.30	.018
Magnesium	201	208	197	205	193	1.0	.44	5
Manganese	33.8 a	49.2 ab	45.7 ab	64.7 b	87.5 c	3.3	.01	4
Nickel	.39 ab	.40 a	.31 abc	.24 bc	.18 c	2.6	.04	.026
Nitrogen	508 a	451 bc	463 b	420 c	419 c	4.5	.00	6
	(23)	(31)	(35)	(41)	(32)			
Phosphorus	34	35	31	31	36	.5	.71	1
	(19)	(30)	(32)	(40)	(29)			
Potassium	648 ab	785 a	631 b	732 ab	597 b	2.7	.03	23
Sodium	2.8 a	5.8 c	5.6 bc	4.7 abc	3.7 ab	2.0	.09	.328
	(19)	(30)	(32)	(40)	(29)			
Sulfur	79 a	75 ab	77 a	70 c	71 bc	3.8	.01	1
	(23)	(31)	(36)	(41)	(32)			
Zinc	11.9 a	12.3 a	14.4 bc	15.9 c	13.6 ab	6.7	.00	.347

[1] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[2] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[3] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 17.2.—*Mean growth (mm), ash content (g kg^{-1}), and elemental concentration (mg kg^{-1}) in the 1956-1965 increment of woody tissue of five tree species on 169 plots by forest type across a Lake States deposition gradient. Number of observations in parentheses.*

Element	Forest type[1]					Anova[2]		
	Bf	Sm	Jp	Rp	A	F	P	MSE$^{0.5}$
Growth	23.2 ac[3]	16.4 b	20.9 a	27.6 d	24.5 cd	12.2	0.00	0.519
	(24)	(41)	(39)	(13)	(38)			
Ash	20 a	12 b	12 b	15 c	15 c	43.0	.00	.20
	(21)	(36)	(36)	(17)	(37)			
Aluminum	8.5 a	4.2 b	6.2 c	11.6 d	6.0 c	34.7	.00	.188
	(22)	(37)	(36)	(18)	(36)			
Boron	3.5 ab	4.3 a	1.7 b	5.3 a	3.1 ab	3.5	.01	.361
	(22)	(37)	(36)	(18)	(37)			
Cadmium	.17	.27	.32	.50	.33	2.0	.10	.031
Calcium	1,420 a	1,010 b	700 c	1,040 b	1,350 a	37.5	.00	22
	(22)	(36)	(36)	(18)	(37)			
Chromium	.47 a	.22 b	.25 b	.47 a	.20 b	12.3	.00	.015
Copper	.8 a	.8 a	.5 b	.6 ab	1.2 c	16.5	.00	.029
	(22)	(37)	(36)	(18)	(37)			
Iron	71 a	36 b	43 b	50 b	37 b	4.9	.00	3
Lead	.41 ab	.37 b	.40 b	.55 a	.44 ab	2.0	.10	.018
Magnesium	299 a	142 b	147 b	240 c	237 c	41.8	.00	5
Manganese	78.3 a	57.3 a	57.0 a	139.4 b	8.2 c	24.4	.00	4
Nickel	.35	.30	.31	.31	.24	.8	.54	.026
Nitrogen	369 a	623 b	370 a	455 c	384 a	64.9	.00	6
	(24)	(41)	(39)	(20)	(38)			
Phosphorus	7 a	61 b	18 c	29 c	38 c	88.6	.00	1
	(22)	(37)	(36)	(18)	(37)			
Potassium	1,930 a	610 b	240 c	245 c	669 b	137.3	.00	23
Sodium	1.1 a	.7 ab	.6 c	.9 bc	.6 bc	2.7	.03	.328
	(22)	(37)	(36)	(18)	(37)			
Sulfur	66 a	100 b	52 c	75 d	72 d	110.7	.00	1
	(24)	(41)	(39)	(21)	(38)			
Zinc	12.1 a	6.2 b	15.9 c	14.5 ac	20.4 d	57.8	.00	.347

[1] Forest type: Bf = Balsam fir, Sm = Sugar maple, Jp = Jack pine, Rp = Red pine, A = Aspen.

[2] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[3] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1.—*Mean growth (mm) of three decades of woody tissue for five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	$MSE^{0.5}$
Balsam fir	1	15.0	11.7	12.8	12.6	10.0	0.4	0.78	0.922
	2	16.5	17.4	18.3	19.7	16.9	.3	.89	1.100
	3	22.6	25.5	23.3	26.2	16.8	1.8	.18	1.326
		(1)	(4)	(6)	(8)	(5)			
Sugar maple	1	11.2	10.9	11.7	16.2	12.3	1.7	.16	.753
	2	14.6	13.8	15.0	20.0	14.3	2.0	.11	.830
	3	15.1	17.7	16.5	16.0	16.7	.3	.90	.831
		(8)	(8)	(8)	(9)	(8)			
Jack pine	1	14.7 a[4]	15.0 a	15.0 a	11.9 ab	10.2 b	4.2	.01	.478
	2	18.4 ab	18.7 ab	19.2 a	14.4 bc	12.7 c	3.4	.02	.716
	3	24.2 a	21.3 ab	24.6 a	18.7 ab	15.6 b	2.4	.07	1.101
		(8)	(7)	(8)	(8)	(8)			
Red pine	1	—	22.6	26.2	26.5	25.1	.3	.83	1.403
	2	—	43.2	35.2	31.9	33.4	.7	.56	2.547
			(4)	(8)	(8)	(7)			
	3	—	19.8	34.8	27.9	27.6	.8	.51	2.637
			(2)	(2)	(5)	(4)			
Aspen	1	21.4	20.1	18.2	19.3	19.2	.2	.95	1.166
	2	23.6	25.4	22.6	21.3	25.6	.6	.70	1.101
	3	25.6	25.4	25.1	22.8	23.7	.4	.84	.934
		(6)	(8)	(9)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean ash content (g kg^{-1}) in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE$^{0.5}$
Balsam fir	1	—	18	17	14	18	1.1	0.43	0.90
			(2)	(4)	(2)	(1)			
	2	—	19	20	17	16	.9	.49	.87
			(4)	(4)	(5)	(3)			
	3	19 ab	23 b	19 ab	18 a	19 ab	2.5	.08	.58
		(1)	(4)	(5)	(8)	(3)			
Sugar maple	1	12	11	11	13	12	.7	.62	.45
		(4)	(6)	(5)	(7)	(6)			
	2	12	11	11	12	11	1.0	.45	.33
		(6)	(7)	(6)	(7)	(7)			
	3	14	12	12	13	10	1.5	.23	.47
		(4)	(8)	(8)	(8)	(8)			
Jack pine	1	12	11	12	13	13	.2	.91	.68
		(7)	(6)	(8)	(4)	(4)			
	2	12	13	13	12	13	.6	.68	.29
		(8)	(7)	(8)	(4)	(4)			
	3	12	12	12	11	11	1.3	.31	.26
		(8)	(6)	(8)	(7)	(7)			
Red pine	1	—	15	15	13	13	1.1	.38	.45
		—	(4)	(8)	(8)	(7)			
	2	—	14	16	15	14	1.3	.31	.54
		—	(3)	(8)	(8)	(7)			
	3	—	14	16	15	16	.4	.72	.70
		—	(3)	(3)	(7)	(4)			
Aspen	1	14	14	12	13	12	.6	.69	.43
		(5)	(8)	(7)	(9)	(6)			
	2	14	13	15	13	14	.9	.48	.45
		(6)	(7)	(8)	(9)	(6)			
	3	15	15	15	14	15	.3	.88	.33
		(6)	(8)	(8)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability value, MSE$^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg[1]) of aluminum in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	$MSE^{0.5}$
Balsam fir	1	—	13	9	13	10	0.8	0.55	1.225
		—	(2)	(4)	(2)	(2)			
	2	—	11 a[4]	9 a	8 ab	5 b	4.2	.03	.522
		—	(4)	(5)	(5)	(4)			
	3	15 a	12 ab	8 bc	8 c	6 c	4.0	.02	.584
		(1)	(4)	(5)	(8)	(4)			
Sugar maple	1	5 a	4 a	4 a	4 a	3 b	2.8	.05	.196
		(4)	(6)	(6)	(8)	(6)			
	2	4	4	3	4	3	1.8	.16	.202
		(6)	(7)	(7)	(9)	(7)			
	3	6 a	4 ab	4 ab	5 a	3 b	2.5	.06	.238
		(4)	(8)	(8)	(9)	(8)			
Jack pine	1	10	14	14	10	12	1.9	.14	.620
		(7)	(6)	(8)	(4)	(4)			
	2	7	8	8	8	6	1.0	.42	.338
		(8)	(7)	(8)	(4)	(4)			
	3	6	7	6	7	6	2.1	.11	.254
		(8)	(6)	(8)	(7)	(7)			
Red pine	1	—	13 ab	14 ab	16 b	11 a	3.7	.03	.635
	2	—	9	10	9	9	.2	.91	.347
		—	(4)	(8)	(8)	(7)			
	3	—	9	14	13	11	1.8	.19	.807
		—	(4)	(3)	(7)	(4)			
Aspen	1	5	6	5	6	4	.7	.58	.332
		(5)	(8)	(7)	(9)	(6)			
	2	5	5	6	5	4	.9	.47	.263
		(6)	(7)	(8)	(9)	(6)			
	3	5	5	7	7	5	1.5	.23	.325
		(5)	(8)	(8)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg^{-1}) of boron in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE$^{0.5}$
Balsam fir	1	—	1.96	12.43	2.38	2.20	0.4	0.76	4.590
		—	(2)	(4)	(2)	(2)			
	2	—	2.84	9.21	2.03	2.09	1.0	.43	1.818
			(4)	(5)	(5)	(4)			
	3	2.10	2.01	7.94	2.29	2.09	.9	.51	1.307
		(1)	(4)	(5)	(8)	(4)			
Sugar maple	1	5.37 a	3.67 b	3.98 ab	3.43 b	3.04 b	2.8	.05	.210
		(4)	(6)	(6)	(8)	(6)			
	2	9.46 a	3.09 b	3.43 b	2.90 b	2.81 b	4.3	.01	.577
		(6)	(7)	(7)	(9)	(7)			
	3	12.70 a	3.22 b	4.00 b	3.13 b	2.66 b	5.8	.00	.618
		(4)	(8)	(8)	(9)	(8)			
Jack pine	1	1.62	1.75	1.92	1.81	1.82	1.3	.28	.048
		(7)	(6)	(8)	(4)	(4)			
	2	1.57 a	1.58 a	1.80 b	1.70 ab	1.50 a	4.1	.01	.027
		(8)	(7)	(8)	(4)	(4)			
	3	.62 ab	1.67 abc	1.90 c	1.81 bc	1.54 a	3.1	.03	.038
		(8)	(6)	(8)	(7)	(7)			
Red pine	1	—	8.26 ab	14.37 a	2.05 b	1.85 b	2.4	.09	2.049
	2	—	9.20	15.67	2.03	2.05	2.2	.11	2.342
		—	(4)	(8)	(8)	(7)			
	3	—	9.18	11.30	2.19	2.17	1.2	.33	2.026
		—	(4)	(3)	(7)	(4)			
Aspen	1	4.44	2.60	3.25	2.25	2.26	1.1	.37	.355
		(5)	(8)	(7)	(9)	(6)			
	2	3.60	2.12	3.16	2.25	2.35	1.0	.42	.282
		(6)	(7)	(8)	(9)	(6)			
	3	4.32	2.85	3.68	2.38	2.59	1.1	.38	.335
		(6)	(8)	(8)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg^{-1}) of cadmium in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE$^{0.5}$
Balsam fir	1	—	0.08 a[4]	0.21 b	0.21 b	0.15 ab	6.6	0.02	0.011
		—	(2)	(4)	(2)	(2)			
	2	—	.11	.21	.22	.21	1.4	.28	.021
		—	(4)	(5)	(5)	(4)			
	3	0.17	.16	.19	.17	.14	.4	.78	.013
		(1)	(4)	(5)	(8)	(4)			
Sugar maple	1	.05	.40	.09	.18	.13	1.3	.30	.052
		(4)	(6)	(6)	(8)	(6)			
	2	.14	.40	.14	.18	.16	.9	.47	.051
		(6)	(7)	(7)	(9)	(7)			
	3	.57	.13	.20	.20	.41	1.5	.23	.059
		(4)	(8)	(8)	(9)	(8)			
Jack pine	1	.51	.14	.22	.32	.19	.5	.72	.097
		(7)	(6)	(8)	(4)	(3)			
	2	.28	.20	.34	.33	.41	.5	.74	.047
		(8)	(7)	(8)	(4)	(4)			
	3	.17	.50	.25	.36	.36	1.1	.36	.051
		(8)	(6)	(8)	(7)	(7)			
Red pine	1	—	.17	.85	.37	.20	1.6	.22	.128
	2	—	.27	.50	.54	.37	.3	.85	.111
		—	(4)	(8)	(8)	(7)			
	3	—	.22	.70	.67	.33	.6	.62	.150
		—	(4)	(3)	(7)	(4)			
Aspen	1	.14	.16	.16	.18	.34	1.8	.15	.025
		(5)	(8)	(7)	(9)	(6)			
	2	.14	.77	.31	.28	.24	.7	.59	.126
		(6)	(7)	(8)	(9)	(6)			
	3	.17	.44	.38	.35	.28	.4	.81	.069
		(6)	(8)	(8)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg^{-1}) of calcium in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE$^{0.5}$
Balsam fir	1	—	665	629	919	1,120	2.3	0.18	75
		—	(2)	(4)	(2)	(2)			
	2	—	1,570	1,110	1,080	1,200	1.4	.29	94
		—	(4)	(5)	(5)	(4)			
	3	3,010 a[4]	1,740 b	1,320 bc	1,200 c	1,240 bc	6.3	.00	80
		(1)	(4)	(5)	(8)	(4)			
Sugar maple	1	889	836	812	756	771	1.3	.28	20
		(4)	(6)	(6)	(8)	(6)			
	2	1,010 a	900 ab	802 b	803 b	852 ab	2.5	.06	24
		(6)	(7)	(7)	(9)	(7)			
	3	1,040	1,140	930	1,000	953	1.3	.29	33
		(3)	(8)	(8)	(9)	(8)			
Jack pine	1	536	562	564	518	535	.7	.63	11
		(7)	(6)	(8)	(4)	(4)			
	2	665	679	687	721	678	.5	.75	12
		(8)	(7)	(8)	(4)	(4)			
	3	692	717	701	697	698	.1	.99	16
		(8)	(6)	(8)	(7)	(7)			
Red pine	1	—	599	622	635	654	.4	.72	16
	2	—	841	918	903	934	.3	.83	31
		—	(4)	(8)	(8)	(7)			
	3	—	1,010	1,070	1,080	969	.4	.74	41
		—	(4)	(3)	(7)	(4)			
Aspen	1	914	1,130	945	803	1,010	1.4	.26	49
		(5)	(8)	(7)	(9)	(6)			
	2	1,120	1,050	1,070	947	1,120	2.1	.11	23
		(6)	(7)	(8)	(9)	(6)			
	3	1,710 a	1,300 b	1,360 b	1,160 b	1,330 b	3.4	.02	47
		(6)	(8)	(8)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg^{-1}) of cadmium in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE$^{0.5}$
Balsam fir	1	—	0.08 a[4]	0.21 b	0.21 b	0.15 ab	6.6	0.02	0.011
		—	(2)	(4)	(2)	(2)			
	2	—	.11	.21	.22	.21	1.4	.28	.021
		—	(4)	(5)	(5)	(4)			
	3	0.17	.16	.19	.17	.14	.4	.78	.013
		(1)	(4)	(5)	(8)	(4)			
Sugar maple	1	.05	.40	.09	.18	.13	1.3	.30	.052
		(4)	(6)	(6)	(8)	(6)			
	2	.14	.40	.14	.18	.16	.9	.47	.051
		(6)	(7)	(7)	(9)	(7)			
	3	.57	.13	.20	.20	.41	1.5	.23	.059
		(4)	(8)	(8)	(9)	(8)			
Jack pine	1	.51	.14	.22	.32	.19	.5	.72	.097
		(7)	(6)	(8)	(4)	(3)			
	2	.28	.20	.34	.33	.41	.5	.74	.047
		(8)	(7)	(8)	(4)	(4)			
	3	.17	.50	.25	.36	.36	1.1	.36	.051
		(8)	(6)	(8)	(7)	(7)			
Red pine	1	—	.17	.85	.37	.20	1.6	.22	.128
	2	—	.27	.50	.54	.37	.3	.85	.111
		—	(4)	(8)	(8)	(7)			
	3	—	.22	.70	.67	.33	.6	.62	.150
		—	(4)	(3)	(7)	(4)			
Aspen	1	.14	.16	.16	.18	.34	1.8	.15	.025
		(5)	(8)	(7)	(9)	(6)			
	2	.14	.77	.31	.28	.24	.7	.59	.126
		(6)	(7)	(8)	(9)	(6)			
	3	.17	.44	.38	.35	.28	.4	.81	.069
		(6)	(8)	(8)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg^{-1}) of calcium in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE$^{0.5}$
Balsam fir	1	—	665	629	919	1,120	2.3	0.18	75
		—	(2)	(4)	(2)	(2)			
	2	—	1,570	1,110	1,080	1,200	1.4	.29	94
		—	(4)	(5)	(5)	(4)			
	3	3,010 a[4]	1,740 b	1,320 bc	1,200 c	1,240 bc	6.3	.00	80
		(1)	(4)	(5)	(8)	(4)			
Sugar maple	1	889	836	812	756	771	1.3	.28	20
		(4)	(6)	(6)	(8)	(6)			
	2	1,010 a	900 ab	802 b	803 b	852 ab	2.5	.06	24
		(6)	(7)	(7)	(9)	(7)			
	3	1,040	1,140	930	1,000	953	1.3	.29	33
		(3)	(8)	(8)	(9)	(8)			
Jack pine	1	536	562	564	518	535	.7	.63	11
		(7)	(6)	(8)	(4)	(4)			
	2	665	679	687	721	678	.5	.75	12
		(8)	(7)	(8)	(4)	(4)			
	3	692	717	701	697	698	.1	.99	16
		(8)	(6)	(8)	(7)	(7)			
Red pine	1	—	599	622	635	654	.4	.72	16
	2	—	841	918	903	934	.3	.83	31
		—	(4)	(8)	(8)	(7)			
	3	—	1,010	1,070	1,080	969	.4	.74	41
		—	(4)	(3)	(7)	(4)			
Aspen	1	914	1,130	945	803	1,010	1.4	.26	49
		(5)	(8)	(7)	(9)	(6)			
	2	1,120	1,050	1,070	947	1,120	2.1	.11	23
		(6)	(7)	(8)	(9)	(6)			
	3	1,710 a	1,300 b	1,360 b	1,160 b	1,330 b	3.4	.02	47
		(6)	(8)	(8)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg^{-1}) of chromium in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE$^{0.5}$
Balsam fir	1	—	0.53	0.20	1.42	0.81	1.9	0.23	0.193
		—	(2)	(4)	(2)	(2)			
	2	—	.35 a[4]	.14 a	.93 b	.62 ab	3.7	.04	.092
		—	(4)	5)	(5)	(4)			
	3	0.58	.42	.30	.61	.47	1.2	.36	.057
		(1)	(4)	(5)	(8)	(4)			
Sugar maple	1	.38 ab	.30 a	.22 a	.41 ab	.72 b	3.0	.04	.049
		(4)	(6)	(6)	(8)	(6)			
	2	.37	.25	.13	.22	.28	1.3	.28	.032
		(6)	(7)	(7)	(9)	(7)			
	3	.31	.18	.16	.25	.25	.9	.47	.027
		(4)	(8)	(8)	(9)	(8)			
Jack pine	1	.25	.46	.40	.36	.45	.84	.51	.378
		(7)	(6)	(8)	(4)	(4)			
	2	.20	.28	.28	.23	.23	.63	.65	.021
		(8)	(7)	(8)	(4)	(4)			
	3	.16 a	.17 ab	.21 ab	.39 c	.32 bc	3.18	.03	.025
		(8)	(6)	(8)	(7)	(7)			
Red pine	1	—	1.03 ab	.41 a	1.10 b	.46 ab	2.4	.10	.121
	2	—	.38	.41	.70	.51	1.7	.19	.054
		—	(4)	(8)	(8)	(7)			
	3	—	.35	.36	.62	.43	1.3	.30	.060
		—	(4)	(3)	(7)	(4)			
Aspen	1	.34	.30	.45	.39	.21	.8	.51	.045
		(5)	(8)	(7)	(9)	(6)			
	2	.26	.14	.22	.20	.14	.9	.46	.023
		(6)	(7)	(8)	(9)	(6)			
	3	.20	.21	.26	.15	.15	.9	.45	.021
		(6)	(8)	(8)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg^{-1}) of copper in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE$^{0.5}$
Balsam fir	1	—	0.96	1.61	1.22	1.44	0.6	0.61	0.179
		—	(2)	(4)	(2)	(2)			
	2	—	.80	.92	.73	.78	.8	.53	.049
		—	(4)	(5)	(5)	(4)			
	3	0.87	.72	1.04	.76	.56	1.8	.17	.059
		(1)	(4)	(5)	(8)	(4)			
Sugar maple	1	1.20	1.69	1.33	.99	1.55	1.9	.14	.094
		(4)	(6)	(6)	(8)	(6)			
	2	.95 ab[4]	1.07 a	.78 bc	.64 c	.69 bc	4.3	.01	.039
		(6)	(7)	(7)	(9)	(7)			
	3	1.35 a	.95 ab	.81 b	.54 b	.63 b	2.9	.04	.069
		(4)	(8)	(8)	(9)	(8)			
Jack pine	1	.84	.97	.85	.88	.80	.4	.80	.042
		(7)	(6)	(8)	(4)	(4)			
	2	.58	.63	.59	.56	.44	1.8	.39	.027
		(8)	(7)	(8)	(4)	(4)			
	3	.49	.51	.45	.60	.48	1.6	.19	.021
		(8)	(6)	(8)	(7)	(7)			
Red pine	1	—	1.12	1.12	1.22	1.04	.8	.48	.041
	2	—	.90	.77	.65	.74	2.1	.13	.033
		—	(4)	(8)	(8)	(7)			
	3	—	.66	.77	.58	.53	.7	.57	.056
		—	(4)	(3)	(7)	(4)			
Aspen	1	1.36	1.45	1.66	1.36	1.31	1.8	.16	.046
		(5)	(8)	(7)	(9)	(6)			
	2	1.06	.92	1.35	1.07	1.14	1.5	.23	.059
		(6)	(7)	(8)	(9)	(6)			
	3	1.27	1.12	1.46	.94	.98	1.6	.20	.077
		(6)	(8)	(8)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg^{-1}) of iron in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE$^{0.5}$
Balsam fir	1	—	352	32	252	216	1.4	0.33	61
		—	(2)	(4)	(2)	(2)			
	2	—	77 ab[4]	27 a	164 b	78 ab	4.2	.02	15
		—	(4)	(5)	(5)	(4)			
	3	94 ab	86 b	23 a	87 b	81 b	2.8	.06	8
		(1)	(4)	(5)	(8)	(4)			
Sugar maple	1	113	78	48	75	84	1.1	.38	9
		(4)	(6)	(6)	(8)	(6)			
	2	56	34	19	45	36	1.9	.14	4
		(6)	(7)	(7)	(9)	(7)			
	3	50 ab	24 a	25 a	52 b	36 ab	2.7	.05	4
		(4)	(8)	(8)	(9)	(8)			
Jack pine	1	86	69	66	81	52	.9	.48	6
		(7)	(6)	(8)	(4)	(4)			
	2	59	57	46	55	26	.8	.52	6
		(8)	(7)	(8)	(4)	(4)			
	3	45	45	34	65	26	1.0	.44	7
		(8)	(6)	(8)	(7)	(7)			
Red pine	1	—	97	59	127	49	1.9	.15	14
	2	—	50	43	83	41	1.0	.40	10
		—	(4)	(8)	(8)	(7)			
	3	—	41	48	67	34	.6	.66	11
		—	(4)	(3)	(7)	(4)			
Aspen	1	108 a	63 bc	78 ab	75 ab	33 c	4.2	.01	5
		(5)	(8)	(7)	(9)	(6)			
	2	59 a	28 b	37 b	31 b	19 b	3.6	.02	3
		(6)	(7)	(8)	(9)	(6)			
	3	60 a	39 bc	42 ab	28 bc	19 c	4.5	.01	3
		(6)	(8)	(8)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg^{-1}) of lead in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE$^{0.5}$
Balsam fir	1	—	0.97	0.92	0.56	0.34	0.6	0.61	0.179
		—	(2)	(4)	(2)	(2)			
	2	—	.34 a[4]	.56 b	.32 a	.45 ab	3.0	.06	.033
		—	(4)	(5)	(5)	(4)			
	3	0.26	.51	.44	.34	.47	.8	.56	.042
		(1)	(4)	(5)	(8)	(4)			
Sugar maple	1	.26 a	.88 b	.23 a	.33 a	.68 b	6.7	.00	.049
		(4)	(6)	(6)	(8)	(6)			
	2	.29	.42	.28	.32	.32	.9	.50	.026
		(6)	(7)	(7)	(9)	(7)			
	3	.34	.35	.35	.43	.37	.3	.89	.034
		(4)	(8)	(8)	(9)	(8)			
Jack pine	1	.29	.52	.66	.86	.39	2.1	.11	.066
		(7)	(6)	(8)	(4)	(4)			
	2	.34	.82	.54	.34	.42	1.3	.30	.081
		(8)	(7)	(8)	(4)	(4)			
	3	.35	.30	.46	.36	.49	1.5	.23	.029
		(8)	(6)	(8)	(7)	(7)			
Red pine	1	—	.88	.46	.64	.46	1.0	.39	.085
	2	—	.87	.85	.61	.46	.6	.61	.123
		—	(4)	(8)	(8)	(7)			
	3	—	.63	.41	.56	.56	.2	.89	.087
		—	(4)	(3)	(7)	(4)			
Aspen	1	.47	.36	.34	.41	.30	.6	.65	.034
		(5)	(8)	(7)	(9)	(6)			
	2	.54	.35	.96	.49	.39	1.4	.26	.095
		(6)	(7)	(8)	(9)	(6)			
	3	.32 a	.31 a	.61 b	.47 ab	.44 ab	3.3	.02	.031
		(6)	(8)	(8)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg^{-1}) of magnesium in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE$^{0.5}$
Balsam fir	1	—	120	101	188	251	3.1	0.11	19
		—	(2)	(4)	(2)	(2)			
	2	—	288	232	239	262	.4	.73	19
		—	(4)	(5)	(5)	(4)			
	3	582 a[4]	318 b	261 b	281 b	294 b	5.4	.01	14
		(1)	(4)	(5)	(8)	(4)			
Sugar maple	1	137 a	109 ab	107 b	113 ab	134 a	2.3	.09	4
		(4)	(6)	(6)	(8)	(6)			
	2	115 a	112 a	100 a	109 a	174 b	7.5	.00	5
		(6)	(7)	(7)	(9)	(7)			
	3	184	155	109	133	150	1.7	.17	8
		(4)	(8)	(8)	(9)	(8)			
Jack pine	1	125	113	136	122	124	1.4	.27	4
		(7)	(6)	(8)	(4)	(4)			
	2	138	135	145	153	125	.8	.52	4
		(8)	(7)	(8)	(4)	(4)			
	3	154	144	157	138	137	1.7	.17	3
		(8)	(6)	(8)	(7)	(7)			
Red pine	1	—	133	146	145	147	.3	.85	5
	2	—	204	235	216	248	.4	.75	14
		—	(4)	(8)	(8)	(7)			
	3	—	225	259	236	246	.5	.66	9
		—	(4)	(3)	(7)	(4)			
Aspen	1	122	172	163	149	155	1.3	.30	7
		(5)	(8)	(7)	(9)	(6)			
	2	128	156	170	163	154	1.1	.40	7
		(6)	(7)	(8)	(9)	(6)			
	3	212	246	261	237	215	.7	.62	11
		(6)	(8)	(8)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg^{-1}) of manganese in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE$^{0.5}$
Balsam fir	1	—	69	40	49	73	0.4	0.73	12
		—	(2)	(4)	(2)	(2)			
	2	—	118 a[4]	70 ab	43 b	45 b	2.8	.08	10
		—	(4)	(5)	(5)	(4)			
	3	217 a	122 a	59 b	69 b	43 b	5.3	.01	9
		(1)	(4)	(5)	(8)	(4)			
Sugar maple	1	20 a	33 a	39 a	71 ab	98 b	2.6	.06	8
		(4)	(6)	(6)	(8)	(6)			
	2	21 a	29 ab	37 ab	67 bc	89 c	3.8	.01	6
		(6)	(7)	(7)	(9)	(7)			
	3	28 a	39 ab	40 ab	78 bc	85 c	2.8	.04	7
		(4)	(8)	(8)	(9)	(8)			
Jack pine	1	24 a	37 a	32 a	44 a	75 b	4.2	.01	4
		(7)	(6)	(8)	(4)	(4)			
	2	33 a	48 ab	45 ab	63 b	91 c	7.7	.00	3
		(8)	(7)	(8)	(4)	(4)			
	3	36 a	54 ab	49 ab	60 b	90 c	8.2	.00	3
		(8)	(6)	(8)	(7)	(7)			
Red pine	1	—	47 a	67 a	85 ab	117 b	2.6	.07	8
	2	—	71 a	103 a	110 a	188 b	4.5	.01	11
		—	(4)	(8)	(8)	(7)			
	3	—	79 a	134 ab	112 a	251 b	3.6	.04	19
		—	(4)	(3)	(7)	(4)			
Aspen	1	3 a	4 a	5 ab	11 b	5 ab	2.3	.08	1
		(5)	(8)	(7)	(9)	(6)			
	2	3 a	4 a	6 ab	13 b	6 ab	2.4	.08	1
		(6)	(7)	(8)	(9)	(6)			
	3	4 a	5 a	7 ab	15 b	8 ab	2.5	.06	1
		(6)	(8)	(8)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg^{-1}) of nickel in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parenthesis.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE$^{0.5}$
Balsam fir	1	—	0.78	0.20	0.81	0.79	0.9	0.49	0.178
		—	(2)	(4)	(2)	(2)			
	2	—	.56	.33	.59	.47	.5	.68	.084
		—	(4)	(5)	(5)	(4)			
	3	0.23	.47	.30	.40	.24	.6	.70	.056
		(1)	(4)	(5)	(8)	(4)			
Sugar maple	1	1.00	.72	.24	.56	.38	2.1	.11	.083
		(4)	(6)	(6)	(8)	(6)			
	2	.39	.41	.18	.51	.14	1.3	.28	.064
		(6)	(7)	(7)	(9)	(7)			
	3	.39	.41	.36	.25	.13	1.2	.35	.050
		(4)	(8)	(8)	(9)	(8)			
Jack pine	1	.29	.26	.31	.50	.33	1.2	.32	.033
		(7)	(6)	(8)	(4)	(4)			
	2	.40	.28	.19	.24	.18	.5	.72	.059
		(8)	(7)	(8)	(4)	(4)			
	3	.44	.59	.16	.20	.20	1.1	.36	.077
		(8)	(6)	(8)	(7)	(7)			
Red pine	1	—	1.28 a[4]	.76 ab	.62 ab	.18 b	2.6	.08	.123
	2	—	1.15	.96	.38	.26	2.0	.14	.145
		—	(4)	(8)	(8)	(7)			
	3	—	.36	.55	.25	.17	1.1	.38	.068
		—	(4)	(3)	(7)	(4)			
Aspen	1	.40	.26	.39	.34	.22	.8	.54	.039
		(5)	(7)	(7)	(9)	(6)			
	2	.36	.39	.33	.18	.19	.7	.62	.053
		(6)	(7)	(8)	(9)	(6)			
	3	.34	.23	.31	.13	.21	1.2	.33	.034
		(6)	(8)	(8)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg^{-1}) of nitrogen in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE$^{0.5}$
Balsam fir	1	781	730	774	679	640	0.6	0.65	34
		(1)	(4)	(6)	(5)	(5)			
	2	504	428	446	419	359	.9	.46	18
	3	454	344	383	382	336	1.5	.24	11
		(1)	(4)	(6)	(8)	(5)			
Sugar maple	1	889	798	755	730	711	1.8	.15	23
		(7)	(8)	(8)	(8)	(8)			
	2	725 a[4]	632 ab	614 b	548 b	556 b	3.8	.01	16
	3	727 a	642 ab	677 a	552 bc	525 c	5.2	.00	17
		(8)	(8)	(8)	(9)	(8)			
Jack pine	1	629 ab	620 ab	792 c	702 bc	563 a	3.8	.01	20
	2	412	428	474	442	386	2.0	.11	11
	3	351	357	382	378	382	.4	.82	11
		(8)	(7)	(8)	(8)	(8)			
Red pine	1	—	631	627	615	635	.1	.98	19
	2	—	463	472	461	475	.1	.98	15
		—	(4)	(8)	(8)	(7)			
	3	—	440	490	440	458	.4	.78	19
		—	(4)	(5)	(7)	(5)			
Aspen	1	598	515	532	455	509	1.7	.18	17
	2	427	408	397	381	347	1.0	.40	12
	3	435	400	387	344	366	2.0	.12	11
		(6)	(8)	(9)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg^{-1}) of phosphorus in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE$^{0.5}$
Balsam fir	1	—	88	84	88	59	1.1	0.43	6.192
		—	(2)	(4)	(2)	(2)			
	2	—	15 a[4]	15 a	11 ab	5 b	5.0	.02	.993
		—	(4)	(5)	(5)	(4)			
	3	17	3	6	10	3	.7	.59	2.193
		(1)	(4)	(5)	(8)	(4)			
Sugar maple	1	156 a	127 ab	116 b	100 b	110 b	3.9	.01	4.454
		(4)	(6)	(6)	(8)	(6)			
	2	80 a	69 ab	72 a	59 b	71 ab	2.9	.04	1.990
		(6)	(7)	(7)	(9)	(7)			
	3	60	68	63	53	62	1.6	.20	2.106
		(4)	(8)	(8)	(9)	(8)			
Jack pine	1	76	75	83	77	61	1.6	.21	2.647
		(7)	(6)	(8)	(4)	(4)			
	2	40	42	40	43	34	1.3	.30	1.178
		(8)	(7)	(8)	(4)	(4)			
	3	21	19	12	19	22	1.8	.15	1.303
		(8)	(6)	(8)	(7)	(7)			
Red pine	1	—	88	79	94	82	1.4	.27	2.953
	2	—	54	54	55	54	.0	.99	2.238
		—	(4)	(8)	(8)	(7)			
	3	—	21	28	32	35	.4	.75	4.592
		—	(4)	(3)	(7)	(4)			
Aspen	1	115	106	113	85	112	1.5	.24	4.861
		(5)	(8)	(7)	(9)	(6)			
	2	56	46	55	50	58	1.8	.15	1.587
		(6)	(7)	(8)	(9)	(6)			
	3	38	37	36	37	42	.3	.87	1.965
		(6)	(8)	(8)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg[1]) of potassium in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE[0.5]
Balsam fir	1	—	900	801	1,400	2,100	1.2	0.39	268
		—	(2)	(4)	(2)	(2)			
	2	—	1,720	1,380	1,940	1,500	1.2	.35	118
		—	(4)	(5)	(5)	(4)			
	3	2,950	2,250	1,460	1,970	1,860	1.8	.17	127
		(1)	(4)	(5)	(8)	(4)			
Sugar maple	1	909 a[4]	703 b	748 b	672 b	702 b	3.2	.03	21
		(4)	(6)	(6)	(8)	(6)			
	2	732 a	600 ab	604 ab	495 b	515 b	4.1	.01	20
		(6)	(7)	(7)	(9)	(7)			
	3	915 a	673 b	594 b	517 b	509 b	5.2	.00	27
		(4)	(8)	(8)	(9)	(8)			
Jack pine	1	476	467	424	464	454	.5	.71	14
		(7)	(6)	(8)	(4)	(4)			
	2	296	290	269	305	283	.6	.66	8
		(8)	(7)	(8)	(4)	(4)			
	3	260 a	264 a	199 b	227 ab	238 ab	2.7	.05	7
		(8)	(6)	(8)	(7)	(7)			
Red pine	1	—	466	403	422	386	1.9	.16	11
	2	—	334	310	283	280	1.1	.36	11
		—	(4)	(8)	(8)	(7)			
	3	—	254	255	238	241	.1	.97	15
		—	(4)	(3)	(7)	(4)			
Aspen	1	569	708	580	557	670	.9	.46	33
		(5)	(8)	(7)	(9)	(6)			
	2	370	471	456	407	358	.7	.60	26
		(6)	(7)	(8)	(9)	(6)			
	3	603	824	721	622	530	1.6	.21	40
		(6)	(8)	(8)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg[1]) of sodium in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE[0.5]
Balsam fir	1	—	3.78	4.56	17.48	11.78	1.4	0.32	2.586
		—	(2)	(4)	(2)	(2)			
	2	—	5.49	6.21	8.43	3.02	1.2	.36	1.031
		—	(4)	(5)	(5)	(4)			
	3	7.04	10.10	6.97	6.41	4.68	.5	.71	1.145
		(1)	(4)	(5)	(8)	(4)			
Sugar maple	1	8.42	12.52	8.20	6.89	5.45	1.6	.20	.934
		(4)	(6)	(6)	(8)	(6)			
	2	4.63 a[4]	9.66 b	4.09 a	4.99 a	3.06 a	3.5	.02	.602
		(6)	(7)	(7)	(9)	(7)			
	3	5.12	7.88	4.70	3.21	5.25	1.4	.24	.667
		(4)	(8)	(8)	(9)	(8)			
Jack pine	1	3.60 a	3.67 a	16.92 b	15.52 b	10.28 ab	6.4	.00	1.176
		(7)	(6)	(8)	(4)	(4)			
	2	3.22	3.16	8.02	6.90	5.40	2.2	.10	.713
		(8)	(7)	(8)	(4)	(4)			
	3	1.65	2.04	3.97	5.91	2.82	1.9	.14	.557
		(8)	(6)	(8)	(7)	(7)			
Red pine	1	—	13.79 ab	10.84 b	23.67 a	6.51 b	2.7	.07	2.353
		—	(4)	(4)	(8)	(5)			
	2	—	11.60 a	6.22 ab	3.75 b	3.47 b	2.9	.06	.934
		—	(4)	(8)	(8)	(7)			
	3	—	5.92	4.00	3.97	1.57	.9	.47	.893
		—	(4)	(3)	(7)	(4)			
Aspen	1	6.30	5.51	12.79	6.15	2.56	1.9	.14	1.215
		(5)	(8)	(7)	(8)	(6)			
	2	5.10	2.70	5.72	3.82	2.90	1.1	.36	.557
		(6)	(7)	(8)	(9)	(6)			
	3	2.02 a	4.37 ab	7.71 b	4.16 ab	3.61 a	2.3	.08	.605
		(6)	(8)	(8)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, $MSE^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg^{-1}) of sulfur in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE$^{0.5}$
Balsam fir	1	75.0	86.7	84.5	79.2	77.0	0.7	0.61	2.277
	2	64.4	74.6	69.1	62.8	62.2	2.0	.14	1.636
	3	69.7 abc[4]	73.8 b	69.3 bc	63.4 ac	59.8 a	2.9	.05	1.441
		(1)	(4)	(6)	(8)	(5)			
Sugar maple	1	109.1	99.6	99.7	98.8	102.0	1.0	.42	1.879
	2	99.5 a	94.5 ab	94.2 ab	88.8 b	84.6 b	2.7	.04	1.545
	3	109.2a	102.6 a	102.4 a	97.8 ab	89.2 b	2.8	.04	1.956
		(8)	(8)	(8)	(9)	(8)			
Jack pine	1	74.5 ab	67.7 b	83.9 a	73.1 ab	77.2 ab	2.1	.10	1.785
	2	57.4	52.7	59.6	55.3	58.3	1.5	.23	.969
	3	52.3 ab	49.1 a	54.1 b	48.3 a	54.3 b	3.0	.03	.727
		(8)	(7)	(8)	(8)	(8)			
Red pine	1	—	83.6	80.4	75.3	76.8	.8	.52	1.947
	2	—	68.4	79.5	67.9	69.5	1.1	.36	2.725
		—	(4)	(8)	(8)	(7)			
	3	—	71.7	87.0	71.1	71.9	1.6	.23	3.041
		—	(4)	(5)	(7)	(5)			
Aspen	1	71.8	70.0	70.5	64.1	74.3	1.1	.39	1.651
	2	67.0	63.8	64.3	59.5	68.6	.7	.60	1.861
	3	74.2	73.1	73.9	66.3	77.1	1.0	.41	1.813
		(6)	(8)	(9)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

Table 18.1 Continued.—*Mean concentration (mg kg^{-1}) of zinc in three decades of woody tissue of five tree species on 169 plots by zone across a Lake States sulfate deposition gradient. Number of observations in parentheses.*

Species	Growth[1] period	Zone[2] 1	2	3	4	5	Anova[3] F	P	MSE$^{0.5}$
Balsam fir	1	—	8 a[4]	9 a	28 b	15 c	137.5	0.00	0.360
		—	(2)	(4)	(2)	(2)			
	2	—	10	10	16	10	1.3	.30	1.239
		—	(4)	(5)	(5)	(4)			
	3	16	10	13	13	12	.4	.82	1.136
		(1)	(4)	(5)	(8)	(4)			
Sugar maple	1	5	5	6	7	5	1.0	.45	.506
		(4)	(6)	(6)	(8)	(6)			
	2	4	6	5	7	5	1.2	.32	.449
		(6)	(7)	(7)	(9)	(7)			
	3	4	6	6	8	5	1.4	.26	.474
		(4)	(8)	(8)	(9)	(8)			
Jack pine	1	10 a	14 ab	20 c	19 bc	15 abc	5.8	.00	.836
		(7)	(6)	(8)	(4)	(4)			
	2	11 a	14 ab	17 b	22 c	17 b	7.6	.00	.626
		(8)	(7)	(8)	(4)	(4)			
	3	12 a	14 ab	16 bc	20 d	19 cd	6.1	.00	.606
		(8)	(6)	(8)	(7)	(7)			
Red pine	1	—	11 ab	14 ab	18 b	10 a	2.5	.09	1.116
	2	—	11	14	16	14	2.3	.10	.602
		—	(4)	(8)	(8)	(7)			
	3	—	11 a	16 b	16 b	15 ab	3.7	.04	.548
		—	(4)	(3)	(7)	(4)			
Aspen	1	17	19	20	22	15	.7	.63	1.482
		(5)	(8)	(7)	(9)	(6)			
	2	11 a	14 ab	16 bc	19 c	16 abc	3.2	.03	.741
		(6)	(7)	(8)	(9)	(6)			
	3	16	19	22	24	20	1.9	.14	.950
		(6)	(8)	(8)	(9)	(6)			

[1] Growth period: 1 = 1976-1985, 2 = 1966-1975, and 3 = 1956-1965 radial growth of wood tissue.

[2] Zones: Sampling zones 1 through 5 from northwestern Minnesota to southeastern Michigan.

[3] ANOVA: F = F value, P = probability, MSE$^{0.5}$ = square root of mean square error.

[4] Values in the same row followed by the same letter are not significantly different by 95 percent LSD multiple range analysis. Test applied only where ANOVA $p<0.10$.

☆U.S. GOVERNMENT PRINTING OFFICE: 1991 - 556-842/40210

Ohmann, Lewis F.; Grigal, David F.
1991. **Properties of soils and tree wood tissue across a Lake States sulfate deposition gradient**. Resour. Bull. NC-130. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 65 p.

Presents the soil and tree wood tissue properties (mostly chemical) of the plots that were remeasured and sampled for a study of the relation between forest condition and wet sulfate deposition along the Lake States acidic deposition gradient.

KEY WORDS: Forest soils, soil sulfur, soil chemistry, tree wood chemistry, forest floor.

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.